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# Biphasic Glycerol/2-MeTHF, Ruthenium-Catalysed Enantioselective Transfer Hydrogenation of Ketones Using Sodium Hypophosphite as Hydrogen Donor

**Carole Guyon,[a] Estelle Métay,[a] Nicolas Duguet,[a] and Marc Lemaire*[a]**

**Keywords:** Reduction / Ketones / Enantioselectivity / Ruthenium

Sodium hypophosphite has been used as an efficient hydrogen donor in the transfer hydrogenation of aliphatic and aromatic ketones in the presence of $[RuCl_2(p\text{-cymene})]_2$ and 2,2′-bipyridine in water. The corresponding alcohols were isolated in moderate to excellent yields (39–95 %). Good chemoselectivity was observed with ester, nitrile and halide functionalities in the ketones not being reduced. An enantioselective version of the reaction using [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}] as catalyst in a glycerol/2-MeTHF biphasic solvent mixture has been developed and allowed the reduction of (hetero)aromatic ketones with excellent chemo- and enantioselectivities (up to 97 % *ee*).

## Introduction

The reduction of ketones is widely employed in the research laboratory as well as in industry.[1] Efficient reduction systems have been developed by using neutral and charged hydrides,[2] molecular hydrogen,[3] hydrogen donors (2-propanol, triethylamine/formic acid, sodium formate),[4] hydrosilanes[5] and hydrosiloxanes.[5]

Molecular hydrogen remains the most attractive reductant in terms of both cost and atom economy. However, the lack of selectivity observed in many cases, the flammability of the gas and the specialized equipment required has led to the search for alternatives. Aluminium and boron hydrides present safety and environmental concerns; they are highly reactive towards air and moisture, and hence careful quenching is usually required to avoid any risk of fire. In addition, the toxicity of the water-soluble solvents used and one of the byproducts are also a serious limitation.[6]

Reduction performed with alcohols (mainly 2-propanol) as the hydrogen donor leads to an equilibrium,[4b] and high dilution is usually preferred to reach high conversions, triethylammonium formate releases unrecyclable triethylamine, and hydrosilanes can disproportionate to $SiH_4$, a pyrophoric and toxic gas.[7] Consequently, the development of new reductive systems that are efficient, selective and cheap (reaction and treatment) with low environmental impact and toxicity is highly desirable. Efforts have been directed towards the use of hydrosiloxanes, which are non-pyrophoric, air-stable and non-toxic reagents. In our group, efficient methods using tetramethyldisiloxane associated with a metal have been developed for the reduction of several functional groups,[8] but the price of this reagent is one of the limitations of its use on an industrial scale.

In our search for other reducing agents we have become interested in sodium hypophosphite[9a] and its derivatives (i.e., phosphinic acid).[9b] Sodium hypophosphite is an easy-to-handle solid, stable to air and moisture, available in bulk quantity and already registered in REACH as a chemical presenting no obvious toxicity.[10]

Sodium hypophosphite and phosphinic acid are known as reducing reagents associated with metal catalysts.[9] In comparison with their large-scale industrial use for electroless nickel plating, for example,[11] they have been less studied for the reduction of functional groups. Sodium hypophosphite derivatives are mainly employed in heterogeneous transfer hydrogenation[12] catalysed by Pd/C[13] or Raney nickel.[14] In contrast, comparatively few examples of homogeneous catalysis with copper,[15] iron[16] and ruthenium have been reported.[14g,17] Reductions catalysed by Pd/C are generally not selective,[18c] but activated ketones are an exception and can be converted into either alcohols[18a] or alkanes.[18b] Iridium tetrachloride in association with phosphinic acid or phosphorus acid in water/*i*PrOH allows the reduction of cyclic ketones with good diastereoselectivities (*cis*/*trans* ratio = 97:3 for 4-*tert*-butylcyclohexanone).[19] A ruthenium-catalysed reduction has also been developed by using triethylammonium hypophosphite as reductant and solvent that gives good stereo- and chemoselectivities.[14g,17b] Despite the efficiency of these methods, they are plagued by the use of water-soluble solvents and the use of excess triethylamine. To the best of our knowledge, no enantioselective reduction of prochiral aromatic and linear aliphatic ketones has been reported by using hypophosphite derivatives as reductant.

[a] Equipe Catalyse Synthèse et Environnement, Institut de Chimie et Biochimie Moléculaires et Supramoléculaires UMR 5246, Université Claude Bernard Lyon 1, Bâtiment Curien, 43 boulevard du 11 novembre 1918, 69622 Villeurbanne Cedex, France
Fax: +33-4-72431408
E-mail: marc.lemaire.chimie@univ-lyon1.fr
Homepage: http://www.icbms.fr/casyen

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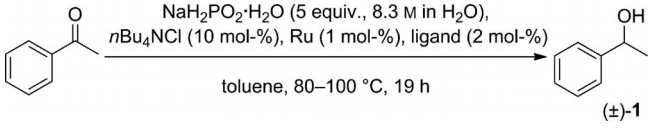
Herein we report the first reduction of ketones to the corresponding racemic alcohols with sodium hypophosphite in a biphasic system using $[RuCl_2(p\text{-cymene})]_2$ and 2,2′-bipyridine. The enantioselective version using the well-known Noyori catalyst [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}] in a 2-MeTHF/glycerol biphasic solvent mixture is also described with good chemo- and enantioselectivities.

## Results and Discussion

Homogeneous ruthenium catalysts are well known for the chemoselective reduction of ketones under transfer hydrogenation conditions.[4] Consequently, we focused our study on ruthenium species as catalysts. Khai and Arcelli[14g,17b] successfully used $[RuCl_2(PPh_3)_3]$ for the reduction of ketones with a triethylamine/phosphinic acid mixture. We were interested in a biphasic version of this reaction with sodium hypophosphite as the reducing agent in water. The reduction of acetophenone by sodium hypophosphite (5 equiv.) catalysed by $[RuCl_2(PPh_3)_3]$ under biphasic conditions (toluene/water) in the presence of a phase-transfer catalyst ($n$Bu$_4$NCl) gave a conversion of 20% (Table 1, Entry 1). The use of water-soluble phosphane ligand TPPTS [tris(*m*-sulfophenyl)phosphane trisodium salt] with $RuCl_3{\cdot}xH_2O$[20] was also evaluated, but did not lead to an improvement of the conversion (Table 1, Entry 2). Nitrogen ligands were also tested with different $Ru^{II}$ and $Ru^{III}$ precursors. The best conversion observed with $RuCl_3{\cdot}xH_2O$ was 42% when 1,10-phenanthroline was used as ligand (Table 1, Entry 3). The reduction was less efficient with the commercially available preformed bipyridine–ruthenium complex $[RuCl_2(biPyr)_2]$ (Table 1, Entry 4). Satisfyingly, the association of 2,2′-bipyridine and the *p*-cymene–Ru complex (1 mol-%) in the absence of toluene and $n$Bu$_4$NCl at 80 °C gave complete conversion of acetophenone (Table 1, Entry 5).

Table 1. Study of the effect of different ruthenium complexes on reduction.



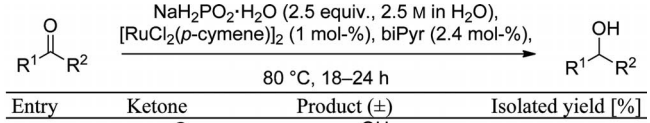

| Entry | Ruthenium complex | Ligand | Conv. [%][a] |
|---|---|---|---|
| 1 | $[RuCl_2(PPh_3)_3]$ | none | 20 |
| 2[b] | $RuCl_3{\cdot}xH_2O$ | TPPTS (4.5 mol-%) | <5 |
| 3 | $RuCl_3{\cdot}xH_2O$ | 1,10-phenanthroline | 42 |
| 4 | $[RuCl_2(biPyr)_2]$ | none | 15–24 |
| 5[b,c] | $[RuCl_2(p\text{-cymene})]_2$ | 2,2′-bipyridine | 98 |

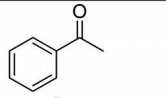
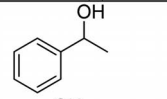
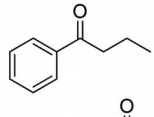
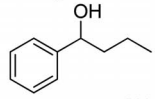
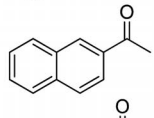
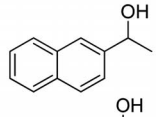
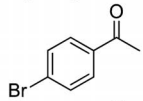
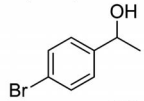
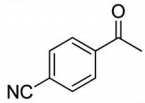
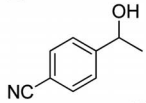
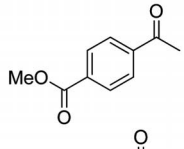
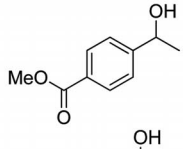
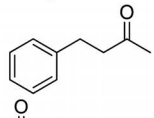
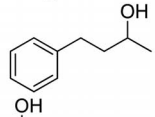
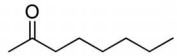
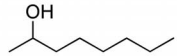
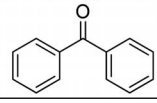
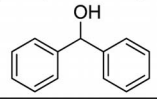
[a] Conversions were determined by $^1$H NMR spectroscopy. [b] No phase-transfer agent or co-solvent was used. [c] 1 mol-% $[RuCl_2(p\text{-cymene})]_2$, 2.4 mol-% 2,2′-bipyridine.

These results indicate that neither a phase-transfer agent nor a co-solvent is necessary to reach high conversions under these conditions. Additional experiments showed that the amount of sodium hypophosphite could be reduced from 5 to 2.5 equiv. without significant loss of conversion. As a consequence, a number of ketones were reduced in water in the presence of 2.5 equiv. sodium hypophosphite with 1 mol-% of $[RuCl_2(p\text{-cymene})]_2$ and 2.4 mol-% of 2,2′-bipyridine at 80 °C for 18–24 h.

The reduction of acetophenone derivatives was not sensitive to the length of the alkyl chain (Table 2, Entries 1 and 2). 2-Acetonaphthone was also converted into alcohol **3** in good yield (Table 2, Entry 3). The reduction was chemoselective towards compounds bearing halogen, nitrile and ester groups under these conditions (Table 2, Entries 4–6). Note that in the case of *p*-cyanoacetophenone and the ester derivative, a co-solvent was necessary to reach good yields and selectivities (Table 2, Entries 5 and 6). Furthermore, alkyl ketones were also reduced and isolated in yields of 75 and 50% (Table 2, Entries 7 and 8). Finally, benzophenone was reduced in 39% yield (Table 2, Entry 9).

Table 2. Reduction of ketones.




| Entry | Ketone | Product (±) | | Isolated yield [%] |
|---|---|---|---|---|
| 1 |  |  | **1** | 90 |
| 2 |  |  | **2** | 85 |
| 3 |  |  | **3** | 74 |
| 4 |  |  | **4** | 71 |
| 5[a] |  |  | **5** | 81 |
| 6[b] |  |  | **6** | 95 |
| 7 |  |  | **7** | 75 |
| 8 |  |  | **8** | 50 |
| 9 |  |  | **9** | 39 |

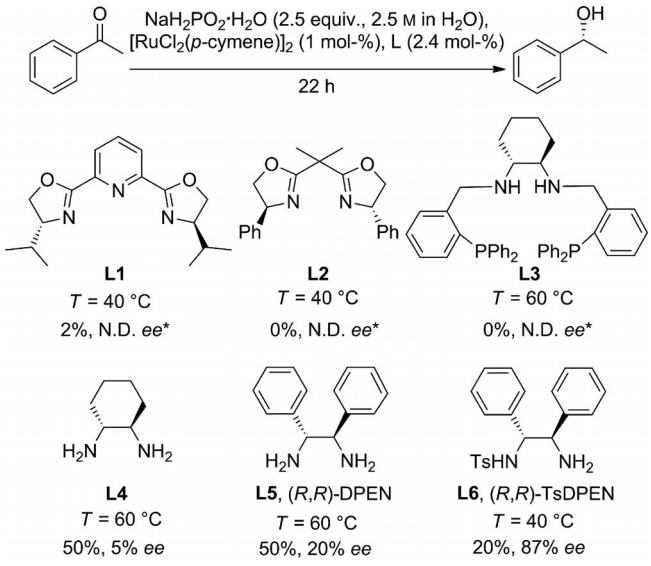
[a] Toluene was used as co-solvent ([S] = 2.5 M). [b] 2-MeTHF was used as co-solvent ([S] = 2 M).

On the basis of these encouraging results, an enantioselective version of this reaction was explored. To the best of our knowledge, there is only one report describing an enantioselective reduction of cyclic ketones with ammonium hypophosphite.[17b] Considering the lack of knowledge on sodium hypophosphite, we considered it of interest

to evaluate its potential in the enantioselective reduction of ketones.

A recent review[21] on enantiopure bipyridines mentioned that the use of these ligands led to relatively poor enantiomeric excesses in the reduction of ketones. Thus, other nitrogen ligands were investigated. All the optimized parameters (2.5 equiv. of $NaH_2PO_2{\cdot}H_2O$ at 2.5 M in water, 1 mol-% of $[RuCl_2(p\text{-cymene})]_2$) were maintained except for the temperature, which was lowered to obtain a better enantiomeric excess. First, the nature of the ligand (2.4 mol-%) was probed (Scheme 1). Oxazoline-based ligands have been reported to induce good enantioselectivity in the hydrosilylation of ketones[22a] and in the transfer hydrogenation with *i*PrOH;[22b] however, they were found to be inefficient in inducing conversion under our conditions (Scheme 1, **L1** and **L2**). The ligand **L3** has been used in asymmetric transfer hydrogenation with formate,[23] but no conversion was observed under our conditions. The reaction performed with cyclohexane-1,2-diamine (**L4**) gave a modest conversion of 50% but a poor enantiomeric excess (5%). Finally, 1,2-diphenyl-1,2-ethylenediamine ligands were engaged in the reduction of acetophenone; $C_2$-symmetric (*R*,*R*)-DPEN (**L5**) gave a moderate yield with 20% enantiomeric excess. Conversely, with Noyori's ligand (*R*,*R*)-TsDPEN (**L6**), 87% *ee* was reached, but with a poor conversion of 20%. This ligand has successfully been used for the reduction of ketones in the presence of the same ruthenium complex in water with sodium formate.[24] Thus, we focused our investigation on Noyori's ligand [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}], which gave the best enantioselectivity.




Scheme 1. Screening of ligands for the reduction reaction. Conversion calculated by $^1$H NMR spectroscopy; *ee* determined by chiral GC; *N.D.: not determined.

Because of the lack of reactivity of the catalyst in water, we considered replacing water by other polar solvents. Data concerning the solubility of sodium hypophosphite are only available for water (51.96 wt.-%) and glycols: ethylene glycol (33.01 wt.-%), glycerol (32.70 wt.-%) and propylene glycol (9.70 wt.-%) at 25 °C.[25] The optimization was pursued with glycerol, which is considered a green solvent according to the GSK's solvent selection guide (Table 3).[26]

A control experiment in the absence of the hypophosphite salt did not lead to any conversion (Table 3, Entry 1). This suggests that glycerol does not act as a hydrogen donor[27] under these conditions. The concentration of hypophosphite in glycerol did not influence the reaction (33% conversion in 15–19 h; Table 3, Entries 2 and 3). However, an increase in the reaction time from 15 to 38 h led to a conversion of 52% and 88% *ee* (Table 3, Entry 3). A further increase in the quantity of sodium hypophosphite from 2.5 to 5 equiv. and its concentration from 2.5 to 5 M did not significantly improve the conversion after 43 h (Table 3, Entry 4). When sodium hypophosphite was replaced by its conjugate acid, the rate of reaction increased, but 3-(1-phenylethoxy)propane-1,2-diol was also formed as a side-product (Table 3, Entry 5). The amount of catalyst had a positive effect on the reaction; an increase in catalyst loading from 2 to 4 mol-% led to an increase in the conversion from 33 to 56% in 14–15 h (Table 3, Entries 3 and 6). When the reaction with 4 mol-% catalyst was performed over 86 h, a conversion of 70% was reached with 90% *ee* (Table 3, Entry 6, in parentheses). As the reaction remained slow, the addition of a co-solvent was considered. In toluene, the reaction was slower than in its absence (Table 3, Entry 7), which can be explained by the competition for coordination to the catalyst between toluene and the substrate. Conversely, 2-MeTHF had a positive effect on the reaction; a

Table 3. Optimization of the reaction conditions using glycerol as protic solvent.[a]

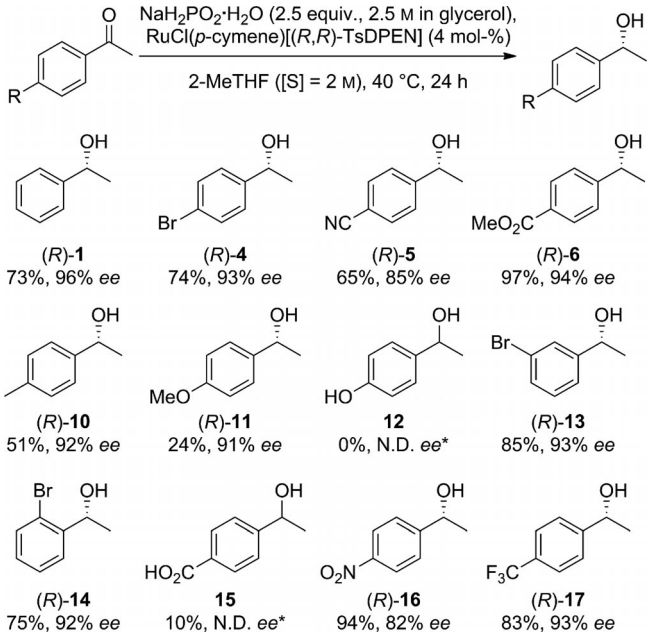
| Entry | Ru. [mol-%] | $NaH_2PO_2{\cdot}H_2O$ [equiv.] | *c* in glycerol [M] | Additive | Time [h] | Conv. [%][b] (conv. [%], *ee* [%][c]) |
|---|---|---|---|---|---|---|
| 1 | 2 | 0 | – | – | 36 | 0 |
| 2 | 2 | 2.5 | 0.71 | – | 19 | 33 |
| 3 | 2 | 2.5 | 2.5 | – | 15 (38) | 33 (52, 88) |
| 4 | 2 | 5 | 5 | – | 43 | 53 |
| 5 | 2 | 2.5 | 2.5 | $H_3PO_2$ (2.5 equiv.) | 17 | 61[d] |
| 6 | 4 | 2.5 | 2.5 | – | 14 (86) | 56 (70, 90) |
| 7 | 4 | 2.5 | 2.5 | toluene ([S] = 2 M) | 14 | 40 |
| 8 | 4 | 2.5 | 2.5 | 2-MeTHF ([S] = 2 M) | 16 (24) | 82 (90, 96) |

[a] Reagents and conditions: acetophenone, $NaH_2PO_2{\cdot}H_2O$, glycerol, [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}], 40 °C. [b] Conversions were determined by $^1$H NMR analysis of the reaction mixture. [c] Conversions and *ee*s determined after the period of time given in parentheses in the preceding column. The *ee*s were determined by chiral GC. [d] Two products were obtained: 1-phenylethanol (49%) and 3-(1-phenylethoxy)propane-1,2-diol (12%).

conversion of 82% was noted along with an enantiomeric excess of 96% in 16 h (Table 3, Entry 8). An increase in the reaction time to 24 h gave a conversion of 90% with 96% *ee* (Table 3, Entry 8). To the best of our knowledge, this biphasic system, glycerol/2-MeTHF, has not been employed previously. Such solvent systems could be advantageously used in other sensitive reactions requiring the separation of the product from other chemical partners. This is in accord with the need to decrease the environmental impact of processes.

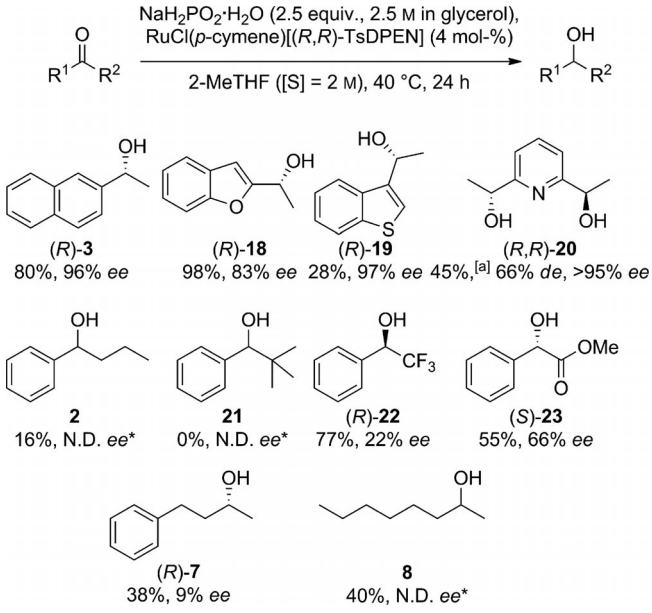
By using these optimized conditions, acetophenone was converted into the corresponding (*R*)-alcohol **1** in 73% yield and 96% *ee* (Scheme 2). Then the scope and limitations of the reaction were investigated. Acetophenones bearing an electron-donating group at the *para* position led to the corresponding alcohols **10** and **11** with excellent enantioselectivities (91–92% *ee*), although in low yields. Similarly, acetophenone derivatives bearing an electron-withdrawing group also led to the products **5**, **6**, **16** and **17** with the same levels of enantioselectivity (82–94% *ee*) but improved isolated yields (65–97%). Within this group of compounds, the nitrile **5** was obtained in the lowest yield (65%) and with *ee* (85%), probably due to the potential ligand effect of the nitrogen atom. Bromoacetophenones were also readily converted into their corresponding alcohols **4**, **13** and **14** with no obvious effect due to the position of the substituent on the aromatic ring. Finally, compounds bearing protic functionalities such as phenol **12** and carboxylic acid **15** afforded low or no conversions. Overall, this method proved to be highly chemoselective as




Scheme 2. Enantioselective reduction of acetophenone derivatives. Isolated yields, *ee* determined by chiral GC or HPLC; configurations were determined by comparison of the measured $[\alpha]_D$ values with the literature data; *not isolated, conversion calculated on the reaction mixture, N.D.: not determined.

halide, nitro,[28] ester, nitrile and ether functional groups were not affected by the reducing agent, while retaining high levels of chiral induction (82–94% *ee*).

The reduction of other ketone derivatives was also investigated (Scheme 3). The reduction of 2-acetonaphthone gave **3** with a comparable conversion and *ee* (80% yield, 96% *ee*) as acetophenone. Ketones bearing heterocycles such as benzo[*b*]furan and benzo[*b*]thiophene led to products **18** and **19** in isolated yields of 98 and 28% and enantiomeric excesses of 83 and 97%, respectively. The reduction of 2,6-diacetylpyridine afforded the corresponding diol **20** in 45% yield and 66% *de*. The major diastereoisomer was isolated with >95% *ee* in favour of the (*R*,*R*) enantiomer. Heteroaromatic ketones bearing a free N–H bond (pyrrole and indole) were also tested, but with no conversion, which confirms the previous observation that protic functional groups are deleterious to the reaction (Scheme 2, products **12** and **15**).




Scheme 3. Enantioselective reduction of ketones. [a] The amount of catalyst, reductive reagent and glycerol were doubled; 81% of the initial mass was recovered after extraction. Isolated yields, *ee* determined by GC or HPLC; configurations were determined by comparison of the measured $[\alpha]_D$ values with the literature data; *not isolated, conversion calculated on the reaction mixture, N.D.: not determined.

Substituents on the alkyl chain were next investigated. The derivatives with medium or bulky alkyl chains were barely reduced to products **2** and **21** (16 and 0% conversion, respectively). Methyl benzoylformate underwent moderate conversion, and the corresponding hydroxy ester **23** was obtained in an isolated yield of 55% with a modest induction of 66% *ee*. The trifluoromethyl derivative **22** was obtained with complete conversion, but the enantiomeric excess was low (22%), and the absolute configuration was attributed to (*R*) by comparison of the measured $[\alpha]_D$ value with the literature data. Thus, the face that was attacked is the opposite to that of other ketones because of the inversion of priority due to the presence of the $CF_3$ group. The loss of

enantiomeric induction with $CF_3$ compared with $CH_3$ has previously been observed in the reduction with [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}] and has been attributed to an attack at the opposite side due to a poor size differentiation between $CF_3$ and the phenyl core.[29] Finally, dialkyl ketones underwent moderate conversion and with low enantiomeric excess (Scheme 3, products **7** and **8**). This can be attributed to the lack of C($sp^2$)–H/π attractive interactions that normally operate between an $\eta^6$-arene ligand and aromatic ketones in the transition state.[30]

## Conclusions

We have developed a general method for the reduction of ketones by using sodium hypophosphite as an efficient hydrogen donor. The transfer hydrogenation of aliphatic and aromatic ketones has been achieved by using an [$RuCl_2$(*p*-cymene)]$_2$/2,2′-bipyridine system in water, and the corresponding alcohols were isolated in moderate to excellent yields (39–95%). Encouraged by these results, we developed an enantioselective version of the reaction by using [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}] in a biphasic glycerol/2-MeTHF solvent mixture. The original conditions allowed the reduction of (hetero)aromatic ketones with excellent enantioselectivities (up to 97% *ee*). The reactions were conducted by using biosourced non-toxic solvents and a cheap reducing agent, sodium hypophosphite, which has been registered in REACH with no obvious toxicity. For these reasons, we believe this reductive system could be of great interest in the context of green chemistry and could be particularly attractive for industrial applications. Current investigations are focused upon expanding the scope of the reaction to a variety of functional groups.

## Experimental Section

**General:** All reagents were obtained from commercial sources and used as received. [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}], 2,2′-bipyridine and $H_3PO_2$ (50% w/w in $H_2O$) were purchased from Sigma Aldrich®. [$RuCl_2$(*p*-cymene)]$_2$ was purchased from Strem Chemicals Inc. and $NaH_2PO_2{\cdot}H_2O$ from Acros Organics. All reactions were performed under argon. Silica gel (40–63 micron) was used for column chromatography. Thin layer chromatography was performed on precoated silica gel 60-F 254 plates. UV light and phosphomolybdic acid were used for analysis of the TLC plates. All compounds were characterized by spectroscopic data. The NMR spectra were recorded with a Bruker ALS or DRX 300 instrument ($^1$H: 300 MHz: $^{13}$C: 75 MHz), chemical shifts are expressed in ppm, *J* values are given in Hz; $CDCl_3$ was used as solvent and internal standard ($\delta$ = 7.26 ppm in $^1$H and $\delta$ = 77.16 ppm in $^{13}$C). The peak patterns are indicated as follows: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; br. broad. Chiral GC was performed on a Shimadzu gas chromatograph GC-14A coupled with an integrator Shimadzu C-R6A Chromatopac by using an Rt®-βDEXm capillary column (30.0 m × 0.25 mm × 0.25 μm) purchased from Restek Chromatography Products and an FID (flame ionisation detector). $N_2$ gas was used as a carrier at 1.75 kg/cm$^2$. Chiral HPLC was performed with a Perkin Elmer Series 200 (pump, UV/VIS detector at 254 nm, vacuum degasser) with a chiral column Chiralcel OJ-H column 0.46 × 25 cm (Daicel Chemical Ind., Ltd.).

**Procedure for the Reduction with [$RuCl_2$(*p*-cymene)]$_2$ and 2,2′-Bipyridine:** In a sealed tube under argon, [$RuCl_2$(*p*-cymene)]$_2$ (15.3 mg, 0.025 mmol, 1 mol-%), 2,2′-bipyridine (9.4 mg, 0.06 mmol, 2.4 mol-%) and sodium hypophosphite monohydrate (662 mg, 6.25 mmol, 2.5 equiv.) were introduced as solids. The ketone (2.5 mmol, 1 equiv.) followed by water (2.5 mL, [$NaH_2PO_2{\cdot}H_2O$] in water = 2.5 M) were then added, and the tube was sealed. The reaction mixture was stirred at 1200 rpm and heated at 80 °C. After 24 h, the tube was cooled to room temperature, depressurized and an aliquot was taken for $^1$H NMR analysis to check the conversion of the starting material. The reaction mixture was diluted by additional water (10 mL) and extracted with either pentane or $CH_2Cl_2$. The combined organic extracts were dried with $Na_2SO_4$, filtered, and concentrated under reduced pressure. The crude material was purified by flash column chromatography on silica gel by using a gradient of pentane or cyclohexane/ethyl acetate (1:0 to 7:3). After concentration, alcohols were obtained as an oil or solid. The products were characterized by NMR spectroscopy (full spectroscopic data are given in the Supporting Information).

**Procedure for the Reduction with [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}]:** $NaH_2PO_2{\cdot}H_2O$ (265 mg, 2.5 mmol, 2.5 equiv.) and glycerol (1 mL) were added to a Schlenk tube. The tube was flushed with argon and, with slow stirring, preformed [RuCl(*p*-cymene){(*R*,*R*)-TsDPEN}] (25.2 mg, 0.04 mmol, 4 mol-%), a ketone (1 mmol, 1 equiv.) and 2-MeTHF (0.5 mL) were quickly added. The reaction mixture was then fluid, and the stirring rate was increased to allow good agitation. The tube was placed in an oil bath preheated to 40 °C, and the reaction mixture was then stirred at 40 °C for 24 h. The subsequent treatment was similar to that described in the previous procedure. The products were characterized by NMR spectroscopy and the *ee*s determined by chiral GC or HPLC (full spectroscopic and chromatographic data are given in the Supporting Information). Configurations were determined by comparison of the measured $[\alpha]_D$ values with the literature data.

**Supporting Information** (see footnote on the first page of this article): Characterization data, NMR spectra, GC and HPLC analyses.

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