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Recoverable dendritic phase-transfer catalysts containing (+)-cinchonine-derived ammonium salts

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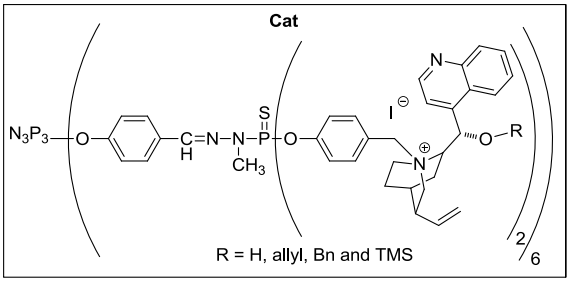


ABSTRACT: Four new phosphorus dendrimeric phase-transfer catalysts are prepared containing on the surface twelve (+)-cinchoninium salts, obtained by quaternisation of the quinuclidinic nitrogen. Asymmetric alkylation of a glycinate Schiff base with benzyl bromide is used as a benchmark reaction, showing that the more active dendrimeric catalyst is the one containing an allyl group on the *O*-9 hydroxy group of the cinchonine units. The recovery and reuse of the catalyst are possible for five consecutive runs without loss of activity and slight decrease in enantioselectivity. When other electrophiles are used, substituted benzyl bromides give better results than other activated alkyl bromides affording the corresponding (*R*)-amino acids derivatives. Comparison of these results with the ones previously reported for similar cinchoninium salts, shows that dendrimers could be a better support than other polymers for this type of organocatalysis.

Introduction

Phase-transfer catalysis (PTC) was reported for the first time by Starks in 1971.[1] This type of catalysis facilitates the migration of a reactant from one phase into another phase where the reaction occurs, avoiding mass transfer limitations and increasing the efficiency of biphasic processes. When the reaction proceeds between an organic and aqueous or solid phase, tetraalkylammonium or phosphonium salts are commonly used as catalysts.[2] This type of catalysis is very versatile for organic synthesis in both academia and industry due to its simple experimental process, mild reaction conditions, inexpensive and sustainable catalysts and solvents, and the possibility to be implemented in large-scale.[3] The asymmetric version has been developed during the last 20 years,[4] being applied in several chemical transformations, such as alkylations,[5] Michael additions,[6] aldol and related reactions,[7] cyclopropanations,[8] epoxidations,[9] aziridinations,[10] among others.[11]

Cheap commercially available *Cinchona* alkaloids and their derivatives have been used as chiral resolving agents,[12] though its extraordinary ability resides in promoting asymmetric transformations, in homogeneous or heterogeneous media, as organocatalysts or chiral ligands.[13] The *N*-alkylation on the quinuclidinic ring generates a variety of quaternary ammoni-

um salts that have been used extensively in asymmetric PTC.[13,14,3]

Phase-transfer alkylation of protected glycine derivatives is a good method to afford optically active α-amino acid precursors, and it is one of the most important reactions studied with *Cinchona* alkaloids derived ammonium salts. It is used as a benchmark reaction for examining the performance of new phase-transfer catalysts.[4,14] O'Donnell in 1989 reported the first example of glycine imine ester alkylation with moderate enantioselectivity levels (up to 66 % enantiomeric excess, ee).[15] Simple modifications on *Cinchona* derivatives allowed Corey[16] and Lygo[17] to obtain impressive degrees of enantioselectivity. Further generations of *Cinchona* ammonium salts as catalysts have been proposed by connecting two or three independent cinchona alkaloid units attached to spacers or modifying electronic effects in the surroundings of quinuclidine *N*-atom.[14] The recovering and reuse (up to the fourth cycle) of these type of catalysts have been done mainly by their attachment to polymers.[18] While a variety of points are present on the *Cinchona* alkaloid motif for anchoring the catalyst on a solid support, attachment at the *O-9* hydroxy group or at the nitrogen atom of the quinuclidine moiety of the alkaloid best preserves the enantioselectivity of the catalyst.[19]

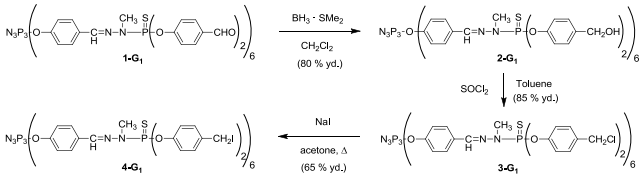
Dendrimers are a new class of polymeric materials with unique structural features such as highly branched and well-defined structure, globular shape, and controlled surface functionalities.[20] Due to their robustness, size and potential dendritic effect,[20.5] they have been used as supports of a large amount of organometallic and organocatalytic moieties (as for example proline derivatives) for catalytic applications, being recovered and reused several times.[20,21] In most of the cases, dendrimers are soluble in the organic media used for the reactions, performing homogeneous catalysis, making possible their easy recovering by precipitation in the reaction media by addition of a non polar solvent. However, *Cinchona* alkaloids have been rarely anchored in these macromolecules.[22, 23] Recently we reported the preparation of two dendrimers of the first and four generation decorated at the surface with 12 and 96 (+)-cinchonine moieties respectively, used as recoverable organocatalysts (up to ten cycles) for the α-amination of several β-dicarbonyl compounds.[22] Nájera, van Koten, and coworkers used Fréchet dendrimers, up to the third generation, containing at the core cinchonine derived ammonium salts for the asymmetric PTC alkylation of *N*-(diphenylmethylene)glycine isopropyl ester with different alkyl halides in good yields but moderate enantioselectivities.[23a] The recovering process using dialysis membranes was only successful for the second generation dendrimeric salts, that were used only for two consecutive catalytic runs.

With these precedents, we planned to decorate, for the first time, a first generation phosphorus dendrimer with different *O*-alkylated (+)-cinchonine ammonium salts and study their catalytic activity and recyclability in the enantioselective PTC alkylation of benzophenone glycine imine *t*-butyl ester with different electrophiles. This reaction is a powerful tool to prepare useful amino acids derivatives and natural products.[24] Catalytic moieties immobilized on the surface of dendrimers are in close proximity, thus allowing a positive or negative effect on the kinetics of the catalyzed reaction (*dendritic effect*) compared to the free ammonium salts. This is analysed in this paper.

Results and discussion

An enormous family of phosphorus dendrimers has been created by the group of Caminade and Majoral.[25] Most of them have been build from hexachlorocyclotriphosphazene as a core, using *p*-hydroxybenzaldehyde and dichlorothiophosphorus monomethylhydrazine in an iterative way, following a divergent method. Aldehyde functions on the surface (**1-G$_1$**) could be reduced with $BH_3{\cdot}SMe_2$ to the corresponding benzyl alcohols (**2-G$_1$**), that after treatment with thionyl chloride in toluene were transformed into the corresponding benzylic chlorides (**3-G$_1$**), under anhydrous conditions, as shown in Scheme 1 for a dendrimer of the first generation.[26]

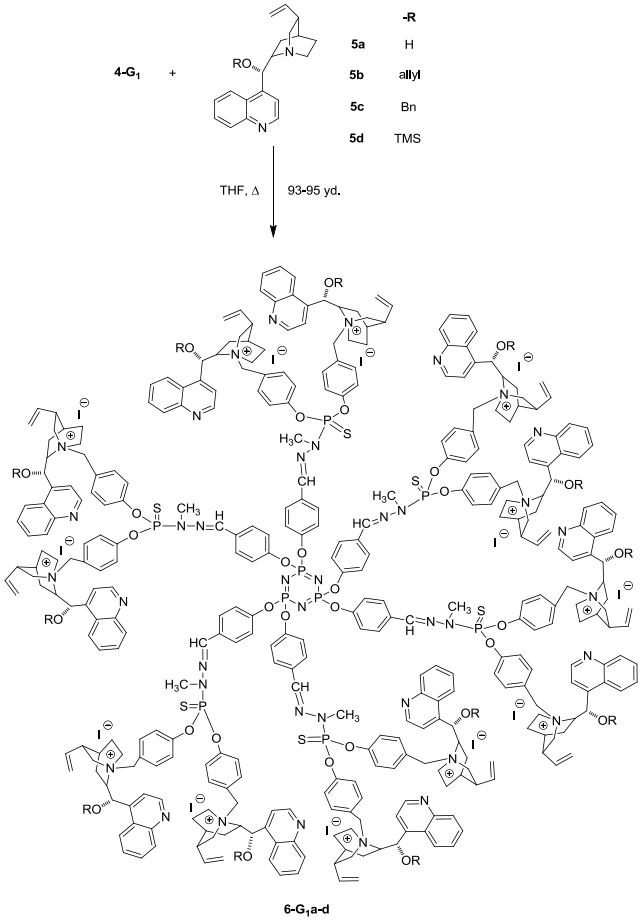
Scheme 1. Synthesis of phosphorus dendrimers containing benzyl chloride and iodide functions on the surface, 3-G$_1$ and 4-G$_1$ respectively.



The next step consisted in the nucleophilic substitution of the chlorine atoms of the outer shell of the dendrimers with commercially available (+)-cinchonine, **5a**, and with other three derivatives resulted from its *O*-9-alkylation with allyl bromide, **5b**, benzyl bromide, **5c**, and trimethylsilyl chloride, **5d**,[27] forming the corresponding quaternary ammonium salts (75-80 % yield.) (Scheme 2). The first reaction was carried out between dendrimer **3-G$_1$** and **5a**, heating in THF and THF-DMF mixtures, however no reaction was observed by NMR (without disappearance of C*H*$_2$Cl at 4.68 ppm, neither change in ^{31}P NMR). Therefore, we decided to modify the surface of the dendrimer changing chlorine atoms by iodine ones, in order to make easier the substitution. The treatment of **3-G$_1$** with a slight excess of sodium iodide, in acetone under reflux for 32 h allowed the formation of **4-G$_1$**, containing 12 iodine atoms on the surface in moderate yields, 77% (Scheme 1). This reaction could be followed by ^{1}H NMR (DMSO-d$_6$), C*H*$_2$Cl groups shifted from 4.67 ppm to 4.54 ppm in C*H*$_2$I. A shift in ^{31}P NMR was also observed from 63.4 ppm to 62.3 ppm, signal corresponding to the external phosphorus atoms.

Dendritic quaternary ammonium salts, **6-G$_1$a-d** were obtained by treatment of the first generation dendrimer **4-G$_1$** with **5a-d** in THF at 70 °C during 24 h, and were isolated by simple filtration with excellent 93-95% yields (Scheme 2). These salts **6** were insoluble in THF at room temperature, whereas starting dendrimer **4-G$_1$** was completely soluble. ^{1}H NMR spectra of ammonium salts in DMSO or CD_2Cl_2 at room temperature afforded complex, broad signals (other solvents were tested showing worst results); even experiments at higher and lower temperatures were performed without better resolution. ^{31} P NMR in DMSO-*d*$_6$ showed in most of the cases a shift from 62.3 ppm (**4-G$_1$**) to 61.1-61.5 ppm in salts; once again, this type of phosphorus NMR experiments was very useful to follow reactions on the surface of dendrimers.

Scheme 2. Preparation of dendrimeric phase transfer catalysts, 6-G$_1$a-d.



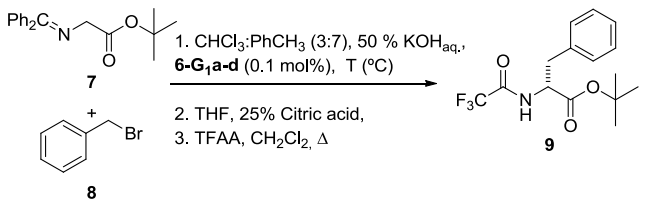
As commented in the introduction, many ammonium salts derived from *Cinchone* alkaloids have been used as catalysts for the asymmetric alkylation of active methylene compounds specially glycine imino esters.[4,14] As a first stage, we decided also to test the catalytic activity of our new dendrimers **6-G$_1$a-d** in the reaction of glycinate **7** with benzyl bromide **8** (Table 1), using the conditions reported by Park, Jew and coworkers.[28] The reaction was performed at room temperature, 0, and −20 °C, using a 50% aqueous solution of KOH in a mixture of $CHCl_3$/toluene (Table 1). The amount of catalyst was reduced compared to the reference article,[28] using 0.1 mol% of catalyst (1.2 mol% of Cinchonine moieties), instead of the 10 % reported. The resulting imines were derivatized to the corresponding trifluoroacetamides, by their hydrolysis with citric acid, and the following protection of the primary amines by reaction with trifluoroacetic anhydride (TFAA). This process was performed to simplify the analysis of the ee by chiral GC, avoiding during the process the hydrolysis and

the corresponding formation of benzophenone, masking the interesting picks on the chromatogram.

The best enantioselectivities were obtained in the reactions catalyzed by **6-G$_1$b**; (*R*)-**9** was obtained as the major isomer, its absolute configuration was determined by chiral GC retention times of both isomers reported previously by some of us for the trifluoroacetamide derivatives.[4,18a,23] The ee was higher at 0 °C (89%) than at rt and at –20 °C (74 and 60%, respectively) (Table 1, entries 2, 6 and 10). In addition, the reaction time increased when temperatures decreased, from 1 h to 8 h. The other three catalysts were in general slightly less enantioselective. However, at 0 ºC benzyl protected cinchonine derivative, **6-G$_1$c**, showed similar activity as **6-G$_1$b** (Table 1, entries 6 and 7). No better results were obtained if a higher amount of catalysts was used. It should be mentioned that when the reaction was performed at – 20 ºC, the reaction media was partially frozen, leading to worse results (Table 1, entries 9–12). By using the best reaction conditions, 0 ºC with catalyst **6-G$_1$b**, we tested other solvents such as toluene alone, a mixture $CHCl_3$:toluene 1:7, dichloromethane or THF, but in all cases the obtained ee's were lower and when DMF was used, racemic mixtures were isolated.

Exploring other organic and inorganic bases such as 2-tert-butylimino-2-diethylamino-1,3-dimethylperhydro-1,3,2-diazaphosphorine (BEMP) and aqueous RbOH, LiOH and NaOH at 0 °C and using **6-G$_1$c** as catalyst similar yields (76–89%) but lower enantioselectivities (12–76%) were obtained. When other bases such as DBU, aqueous Cs_2CO_3 and K_2CO_3 were attempted, no reaction was observed.

Table 1. Catalyst screening at different temperatures[a]



entry	**Cat**[b]	T (ºC)	yield (%)[c]	ee (%)[d]
1	**6-G$_1$a**	25	75	68
2	**6-G$_1$b**	25	80	74
3	**6-G$_1$c**	25	81	70
4	**6-G$_1$d**	25	78	70
5	**6-G$_1$a**	0	73	80
6	**6-G$_1$b**	0	79	89
7	**6-G$_1$c**	0	75	86
8	**6-G$_1$d**	0	70	78
9	**6-G$_1$a**	–20	62	48
10	**6-G$_1$b**	–20	60	60
11	**6-G$_1$c**	–20	66	48
12	**6-G$_1$d**	–20	58	36

[a] Reactions were performed with 0.25 mmol of **7**, 1.26 mmol of **8**, and catalyst **6** (0.1 mol%) in 1.5 mL ($CHCl_3$/$PhCH_3$, 3:7) and 50 % KOH aqueous solution (141 μL), 1–8 h (followed by ^{1}H NMR). [b] Higher catalysts loadings didn't gave better results. [c] Isolated yields after column chromatography, acidic hydrolysis and formation of the trifluoroacetamide. [d] Determined by chiral CG of the isolated product **9**.

In tested conditions, suspensions of our catalysts were observed in the reaction media showing that probably heterogeneous phase-transfer catalysis was performed, although catalysts **6-G$_1$b** and **6-G$_1$c** seemed to be partially soluble. It is known for a family of phosphorus dendrimers containing charged moieties on the surface, as the ones tested, that when only water is used as solvent, generally they are mainly insoluble in spite of the charged surface. However, when some drops of an organic solvent (for example THF or DMF) are added, some molecules of these solvents are incorporated in the internal cavities of the dendrimer, helping to solubilise this apolar part, and promoting its final solubility in aqueous media.[29] Taking into account this behaviour, we could think that one part of all our dendrimers could be soluble in the reaction media tested. When the reactions finished (followed by ^{1}H NMR), catalysts could be recovered by filtration, however, part of them were lost. When diethyl ether was added to the final reaction crudes, complete precipitation of dendrimers was accomplished, and practically the total amount of catalysts was recovered, supporting the previous hypothesis.

The recycling of the most active prepared supported organocatalyst, **6-G$_1$b**, was evaluated. The activity was maintained during five cycles (yields 80-77%) but a slight decrease in enantioselectivity (89-79%) was observed (Table 2). The recovering of the catalyst by simple filtration after complete precipitation by addition of Et_2O, enhanced the role of the dendrimer as support. After the fifth cycle, the catalyst was

analyzed by ^{1}H and ^{31}P NMR confirming that it was a robust macromolecule because its structure was maintained.

Our results for this bench reaction compared with the ones reported in the literature for different modified *Cinchone* alkaloid salts are quite good concerning yields and enantioselectivities, similar ranges being obtained.[14] However, to the best of our knowledge, the activity of our dendrimers compared with supported cinchonine alkaloid in polymers (even in SynPhase™ lanterns) are higher in *ee*, and in addition, the reaction time has been reduced, from several hours to one, in our case at 0 ºC, using only 0.1 mol% of our catalyst (1.2 mol% of cinchonine moieties).[18,19,30] The possibility of the existence of a collaborative effect among the cinchonine moieties on the surface of the dendrimer could be the explanation of this kinetic improvement, showing a positive dendritic effect. This effect does not exist when *Cinchone* derivatives are incorporated at the core of a dendrimer. As reported by some of us, in that case activity and enantioselectivity of the dendritic catalysts were worse and their recyclability was only twice, with low ee.[23a]

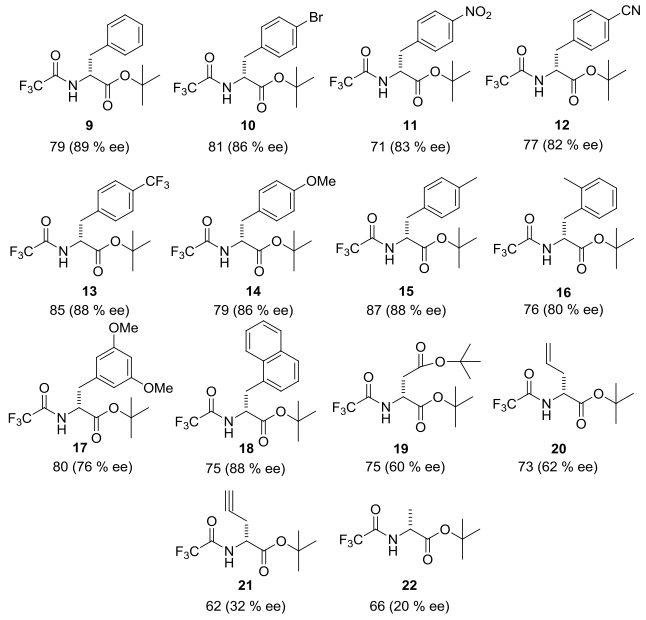
Table 2. Recycling Experiments of Catalyst 6-G$_1$b in the Reaction of Compound 7 with 8 (table 1)[a]

	Catalyst	
	6-G$_1$b[a]	
entry	yield (%)[b]	ee (%)[c]
1	79	89
2	80	86
3	78	82
4	77	81
5	77	79

[a] Reactions were performed with 0.25 mmol of **7**, 1.26 mmol of **8**, and catalyst (0.1 mol%) in 1.5 mL ($CHCl_3$/$PhCH_3$, 3:7) and 50 % KOH aqueous solution (141 μL), 1 h at 0 ºC. [b] Isolated yields after column chromatography, acidic hydrolysis and formation of the trifluoroacetamide. [c] Determined by chiral CG of the isolated product **9**.

The scope of the catalytic enantioselective alkylation of the *N*-(diphenylmethylene)glycine *tert*-butyl ester with various alkylating agents was then evaluated (Figure 1). Taking into account the precedent results, the reactions were performed with **6-G$_1$b**, in the best conditions gathered in Table 1. Different benzyl bromides were used as electrophiles, some of them containing activated and inactivated aromatic rings (products **9-17**, Figure 1). Good yields (76-87%) and enantioselectivities (76-89 %) were obtained, showing no significant influence of the electronic effects of the substituents. When two electrodonating groups were introduced in the electrophile, compound **17** was obtained with lower ee's, compared to compound **14**. However, some steric effects could be also responsible, as observed in the preparation of products **15** and **16**. Nevertheless, the alkylation with 1-(bromomethyl)naphthalene gave good ee's (88 %). The use of other electrophiles, such as *t*-butyl 2-bromoacetate, allyl, progargyl and methyl bromides reduced considerably the ee (**19-22** Figure 1). The (*R*)-configuration of compounds **9-22** was assigned by the relative retention times of the isomers described in the literature.[18a,31] If we compared this results with the ones obtained by some of us for polymer supported cinchonine alkaloid, much better ee's in lower reactions time have been obtained using the chiral dendritic catalyst.[18a]

Figure 1. Substrate Scope for different alkylating agents using supported catalyst 6-G$_1$b. Major isomer obtained represented, yield % (% ee).



Conclusions

We have prepared for the first time four dendrimers containing on the surface 12 quaternary ammonium salts derived from (+)-cinchonine alkaloid (**6-G$_1$a-d)**, by quaternisation of quinuclidinic nitrogen. Dendrimer containing *O*-9-allylated cinchonine moieties, **6-G$_1$b**, was the most active when used as PTC,

only in 1 mol%, for the alkylation of glycine imine *t*-butyl ester as benchmark reaction at 0 ºC. Better yield and enantioselectivity have been obtained compared with the use of *N*-benzylcinchoninium salt for the alkylation with benzyl bromide (O'Donnell's work).[15] Good yields and moderate enantioselectivities were obtained when other electrophiles were tested; differently substituted benzyl bromides gave better results. From these first experiments, comparing once more with the use of polymer-supported cinchonine alkaloid-derived ammonium salts, this phosphorus dendrimer seems to improve activity and enantioselection; the existence of a dendritic effect should not be discarded by a collaborative effect of salts on the surface, not observed when a similar salt was incorporated at the core in previous works.[23a] Moreover, owing to the greater advantages that supported phase-transfer catalysts have for large-scale processes, from both practical and economical aspects, the use of dendrimers seem to be a good and more active alternative to polymers, as shown in this work. The dendrimers were at least used for five cycles, while maintaining their activity and slightly decreasing the enantioselectivity, and maintaining its structure as probed by NMR. To the best of our knowledge, these results are the best reported in the literature for supported *Cinchonine* PTCs. The anchorage of different *N*-alkylated *Cinchone* alkaloids on the surface of dendrimers through the vinyl group should be further studied.

Experimental part

General information

Unless stated otherwise, reactions were performed in oven-dried glassware sealed with rubber septa under a nitrogen atmosphere and were stirred with Teflon-coated magnetic stir bars. Liquid reagents and solvents were transferred via syringe using standard Schlenk techniques. Tetrahydrofuran (THF) and pentane were dried by passage over a column of activated alumina; Dichloromethane was dried by passing through a column of activated molecular sieves using an Innovative Technology PureSolv apparatus. Chloroform was dried over calcium hydride. All other solvents and reagents were used as received unless otherwise noted.

Silica gel was purchased from Scharlau (Silica Gel 60, 230-440 mesh). Thin layer chromatography was performed using silica gel 60 F-254 precoated plates (0.25 mm) and visualized by UV irradiation and potassium permanganate stain. Sorbent silica gel (particle size 40-63 μm) was used for flash chromatography.

The enantiomeric excess (ee) of the products **9-22** were determined by chiral GC analysis[18a,31] (Crown-pack Chiralsil-L-Val column, 25 m x 0.25 mm, conditions P = 85 kPa, 1 min 85 ºC, 2 ºC/min to 180 ºC) of their corresponding *N*-trifluoroacetamide esters. GC reference racemic samples were prepared from the racemic **9-22**, which were obtained using *N*-tetrabutylammonium bromide as PTC catalyst.

All NMR measurements were carried out at the *Servei de Ressonància Magnètica Nuclear at the Universitat Autònoma de Barcelona*. Routine ^{1}H, ^{13}C and ^{31}P NMR spectra were recorded on Bruker AC250 (250 MHz for ^{1}H), Avance360 (360 MHz for 1H) and AV400 (400 MHz for ^{1}H) instruments. ^{1}H NMR chemical shifts are given relative to the residual protic solvent in $CDCl_3$ (7.26 ppm). ^{13}C NMR spectra are given relative to $CDCl_3$ (77.23 ppm).

From the *Servei d'Anàlisi Química of Universitat Autònoma de Barcelona* the following experimental data were acquired: infrared spectra (IR) and specific rotation (ORD). IR was recorded with a Bruker Tensor27 with an ATR Golden. Specific rotation values $[\alpha]_D$ were obtained in a JASCO J-175 polarimeter at 589.6 nm and they are given in 10^{-1} deg cm^2 g^{-1}.

Mass-spectrometry chromatograms (HR-MS) were recorded on a Bruker AutoFlex-III (Bruker Daltoniks, Bremen, Germany) instrument at *Universidad de Zaragoza*.

Elemental analyses were done by the *Serveis d'Anàlisi Química of the Universitat de Autònoma de Barcelona*. Elemental analyses of C, N and H were performed using an elemental analyser EA-1108 CE Instrument of Thermo Fisher Scientific with BBOT as an internal standard.

Melting points were determined using a Koffler-Reichert apparatus and were not corrected.

Abbreviations are as follows: *s* (singlet), *d* (doublet), *t* (triplet), *q* (quartet), *dd* (doublet of doublet), *dt* (doublet of triplet), *pent* (pentet), *hept* (heptet), m (multiplet), *bs* (broad singlet).

Dendrimers **1-G$_1$**, **2-G$_1$**, **3-G$_1$**, alkylated cinchonine **5b-d** and imine **7**, were prepared following the procedures described in the literature.[26,27,32,33] All electrophiles used were commercially available. Products **9-22** were previously described in the literature,[18a,31] ^{1}H, ^{13}C NMR and chiral GC retention time are indicated to probe purity.

Synthesis of new compounds

Synthesis of **4-G$_1$**

Compound **3-G$_1$** (0.50 g, 0.16 mmol) was solubilized in 18 mL of acetone and 13 equivalents of NaI (0.23 g, 1.56 mmol) were added. The temperature was brought up to reflux and the solution was left stirring for 32 hours. After cooling, salts were filtered and the product **4-G$_1$** was recovered through evaporation, and the residue was washed with acetone (10 mL), and THF/pentane mixtures (1:10). 0.52 g (77 % yd.) of a pale orange solid was obtained corresponding to **4-G$_1$**. M.p. > 250 ºC. IR (ATR) ν: 3450, 1603, 1501, 1215, 1193, 1179, 1100, 1017, 914, 839, 780, 753, 731, 698, 641, 622 cm^{-1}. ^{31}P NMR (81 MHz, CH_2Cl_2-d_2) δ: 62.20, 8.51 and in DMSO-d_6 δ: 62.33, 9.48 ppm and (81 MHz, CH_2Cl_2-d_6) 62.20, 8.51 ppm . ^{1}H NMR (250 MHz, CH_2Cl_2-d_2), 3.30 (d, $^3J_{HP}$ = 10.0 Hz, 18 H), 4.42 (s, 24H), 7.05 (d, 12 H), 7.12 (d, $^3J_{HH}$ = 7.5 Hz, 24 H), 7.32 (d, $^3J_{HH}$ = 7.5 Hz, 24 H), 7.66 (br m, 18 H) ppm.^{13}C{^{1}H} NMR (100.6 MHz, CH_2Cl_2-d_2), 4.8, 33.0 (d, $^2J_{CP}$ = 13.8 Hz), 121.5, 121.7, 128.3, 130.1, 132.2, 136.9, 139.0 (d, $^3J_{CP}$ = 13.8 Hz), 149.9 (d, $^2J_{CP}$ = 7.9 Hz), 151.3 (d, C_0^1, $^2J_{CP}$ = 7.9 Hz) ppm. Elemental analysis calculated for $C_{132}H_{120}I_{12}N_{15}O_{18}P_9S_6$: C 37.76; H 2.88 and N 5.00; found: C 37.93; H 3.20 and N 5.32. MALDI-TOF MS (ditranol and NaTFA as matrix) (m/z): found for $[M + H]^+$ 4198 and $[M + Na]^+$ 4221.

*Synthesis of **6-G$_1$a**.*

A mixture of (+)-cinchonine **5a** (0.78 g, 2.64 mmol) and dendrimer **4-G$_1$** (0.93 g, 0.22 mmol) in anhydrous THF (20 mL) was stirred at 70 ºC during 24 h. After cooling the mixture to room temperature, the suspension was filtered and the solid was washed with MeOH (3 x 20 mL), isolating pure **6-G$_1$a** (1.62 g, 95 % yield) as a white solid. M.p. > 250 ºC. α_D^{20} $[\alpha]_D^{20}$ = +35.8 (*c* 1, DMSO). IR (ATR) ν: 3227 (st OH), 2943, 2877, 1658, 1599, 1503, 1458, 1390, 1305, 1199, 1165, 1054, 926, 839, 771, 636 cm^{-1}. ^{31}P NMR (DMSO-d_6, 81.0 MHz, 373 K) δ: 59.8, 6.0. ^{1}H NMR (DMSO-d_6, 400 MHz, 373 K) δ: 0.85 (m, 12 H), 1.22 (m, 12H), 1.38 (m, 12H), 1.56 (m, 24H), 1.77 (m, 24H), 2.04 (m, 12H), 2.35 (m, 12H), 2.40-2.94 (complex absorption, 24H), 3.22 (m, 18H), 3.25-3.57 (complex absorption, 24 H), 3.57 (m, 12H), 5.09 (br s, 24H), 5.57 (br s, 12H), 6.03 (m, 12H), 7-05-7.35 (m, 12H), 7.50-7.75 (complex absorption, 96H), 7.99 (d, *J* = 8.0 Hz, 18H), 8.25 (d, *J* = 12.0 Hz, 12H), 8.81 (s, 12H).^{13}C NMR (DMSO-d_6, 100.6 MHz, 373 K) δ: 23.0, 25.7, 28.3, 39.1, 49.0, 49.6, 50.1, 61.1, 70.1, 70.2, 115.4, 119.4, 124.2, 124.3, 126.3, 126.6, 129.1, 130.1, 130.2, 140.1, 140.5, 140.6, 148.5, 149.5, 150.5, 151.0. Elemental analysis calculated for $C_{360}H_{384}I_{12}N_{39}O_{30}P_9S_6$: C 55.93, H 5.01 and N 7.07; found C 56.15, H 5.27 and N 7.32.

*Synthesis of **6-G$_1$b**.*

A mixture of cinchonine derivative **5b** (0.34 g, 1.00 mmol) and **4-G$_1$** (0.35 g, 0.08 mmol) in anhydrous THF (20 mL) was stirred at 70 ºC during 24 h. After cooling the mixture, the solvent was evaporated under vacuum and then the resulting solid was dissolved in dichloromethane and precipitated with pentane (1:10),isolating by filtration **6-G$_1$b** (0.63 g, 93 % yield) as an pale orange solid. M.p > 250 ºC. $[\alpha]_D^{20}$ = +51.7 (*c* 1, DMSO). IR (ATR) ν: 3416, 2947, 2881, 1603, 1504, 1460, 1422, 1262, 1197, 1162, 1064, 1017, 917, 835, 781, 757, 633 cm^{-1}. ^{31}P NMR (CH_2Cl_2-d_2, 81.0 MHz, 373 K) δ: 61.5, 8.6. ^{1}H NMR (CH_2Cl_2-d_2, 400 MHz, 373 K) δ: 1.09 (bs, 12H), 1.26 (m, 12H), 1.70-1.84 (complex absorption, 24H), 1.98 (m, 12H), 2.39 (m, 12H), 2.49-2.70 (complex absorption, 24H), 2.93 (m, 12H), 3.45-3.57 (complex absorption, 30H), 4.08-4.30 (complex absorption, 36 H), 4.42 (m, 12H), 5.1 (m, 12H), 5.22-5.44 (complex absorption, 48H), 5.93-6.23 (complex absorption, 36H), 7.01 (d, *J* = 8.4 Hz, 12H), 7.40 (m, 24 H), 7.59 (d, *J* = 8.4 Hz, 12H), 7.73-7.84 (complex absorption, 48H), 7.95 (m, 12H), 8.15 (m, 12H), 8.60 (bs, 6H), 8.71 (m, 12H), 8.97 (d, *J* = 12 Hz, 12H) ppm.^{13}C NMR (CH_2Cl_2-d_2, 100.6 MHz, 373 K) δ: 22.0, 23.2, , 26.9, 33.6, 37.2, 54.9, 56.1, 61.2, 66.3, 70.3, 74.2, 117.7, 119.5, 121.2, 121.9, 124.1, 124.9, 126.7, 129.6, 129.6, 130.1, 130.3, 132.1, 132.7, 135.5, 135.72, 139.3, 140.8, 148.5, 149.7, 151.1, 152.1 ppm. Ele-

mental analysis calculated for $C_{396}H_{432}I_{12}N_{39}O_{30}P_9S_6$: C 57.92, H 5.30 and N 6.65; found C 58.20, H, 5.61 and N 9.97.

Synthesis of ***6-G₁c.***

A mixture of cinchonine derivative **5c** (0.39 g, 1.03 mmol) and **4-G₁** (0.37 g, 0.087 mmol) in anhydrous THF (20 mL) was stirred at 70 ºC during 24 h. After cooling the mixture to room temperature, the suspension was filtered and the solid was washed with MeOH (3 x 20 mL), isolating pure **6-G₁c** (0.72 g, 95 % yield) as a white solid. M.p > 250 ºC. $[\alpha]_D^{20}$ = +53.0 (*c* 1, DMSO). IR (ATR) ν: 3423, 3063, 2883, 2837, 2789, 2651, 2586, 1656, 1609, 1502, 1451, 1392, 1355, 1305, 1204, 1167, 1107, 1052, 1025, 924, 840, 761, 700, 666, 636 cm^{-1}. ^{31}P NMR (DMSO-d_6, 81.0 MHz, 373 K) δ: 61.3, 8.3. ^1H NMR (DMSO-d_6, 400 MHz, 373 K) δ: 1.37 (m, 12H), 1.77 (m, 24H), 1.94 (s, 12H), 2.26 (m, 12H), 2.68 (m, 12H), 3.12 (m, 24H), 3.22 (m, 18H), 3.39 (m, 24H), 3.62 (m, 24H), 4.0 (complex absorption, 12H), 4.43 (d, *J* = 12.0 Hz, 12H), 4.55 (d, *J* = 12.0 Hz, 12H), 5.01 (complex absorption, 24H), 5.84 (m, 12H), 6.16 (br s, 12H), 7.00-7.55 (complex absorption, 132H), 7.62 (d, *J* = 4 Hz, 12H), 7.69 (m, 12H), 7.80 (m, 12H), 7.95 (s, 6H), 8.08 (d, *J* = 8 Hz, 12H), 8.39 (d, *J* = 8 Hz, 12H), 8.92 (d, *J* = 4.0 Hz, 12H). ^{13}C NMR (DMSO-d_6, 100.6 MHz, 373 K) δ: 19.0, 23.5, 27.1, 32.0, 36.4, 49.0, 59.6, 60.1, 61.0, 71.2, 75.5 (m), 116.8, 119.5, 123.8, 124.0, 126.0, 127.6, 128.4, 128.6, 128.8, 129.1, 129.9, 137.3, 142.5, 148.6, 150.4, 150.6. Elemental analysis calculated for $C_{444}H_{456}I_{12}N_{39}O_{30}P_9S_6$: C 60.51, H 5.22 and N 6.20; found C 60.83, H 5.56 and N 6.44.

Synthesis of ***6-G₁d.***

A mixture of cinchonine derivative **5d** (0.77 g, 2.1 mmol) and **4-G₁** (0.74 g, 0.18 mmol) in anhydrous THF (20 mL) was stirred at 70 ºC during 24 h. After cooling the mixture to room temperature, the suspension was filtered and the solid was washed with Et_2O (3 x 20 mL), isolating pure **6-G₁d** (1.44 g, 93 % yield) as a white solid. M.p. > 250 ºC. $[\alpha]_D^{20}$ = +17.7 (*c* 1, DMSO). IR (ATR) ν: 3427, 2949, 2890, 2334, 1608, 1503, 1458, 1411, 1302, 1250, 1199, 1165, 1058, 1012, 936, 842, 769, 636 cm^{-1}. ^{31}P NMR (DMSO-d_6, 81.0 MHz, 373 K) δ: 61.1, 8.1. ^1H NMR (DMSO-d_6, 400 MHz, 373 K) δ: - 0.04, - 0.02, 0.01 (s, 108 H), 0.87 (m, 12H), 1.41 (m, 12H), 1.55 (m, 24H), 1.76 (m, 12H), 2.02 (m, 12H), 2.50 (br s, 12H), 2.62-2.90 (complex absorption, 24 H), 3.19 (s, 18H), 3.00-4.00 (complex absorption 48H), 5.11 (complex absoption, 24H), 5.52 (br s, 12H), 6.05 (m, 12H), 7.10-7.95 (complex absorption, 108H), 8.00 (d, *J* = 8.0 Hz, 12H), 8.25 (d, *J* = 8.0 Hz, 12H), 8.82 (s, 12H). ^{13}C NMR (DMSO-d_6, 100.6 MHz, 373 K) δ: 2.1, 22.7, 25.8, 28.0, 39.1, 48.8, 49.6, 61.1, 70.3, 115.2, 119.3, 124.4, 126.3, 126.5, 129.0, 130.1, 140.7, 148.5, 149.7, 150.3. Elemental analysis calculated for $C_{396}H_{480}I_{12}N_{39}O_{30}P_9S_6Si_{12}$: C 55.32, H 5.63 and N 6.35; found C 55.67, H 5.99 and N 6. 54.

General procedure for the alkylation of *N*-(diphenylmethylene)glycine *tert*-butyl ester, 7

To a stirred suspension of **7** (0.25 mmol), the catalysts **6-G₁a-d** (0.1 mol%) and the corresponding base (141 mL) in the appropriate solvent (1.5 mL) at selected temperature, was added the corresponding alkylating agent (1.26 mmol). When the reaction was finished (^1H-NMR), 5 mL of Et_2O were added in order to precipitate completely the catalyst, the mixture was filtered and the solid was washed with Et_2O (2 x 10 mL), recovering the catalyst for further use. The recovered catalysts were analyzed by ^{31}P NMR. The filtrated was washed with water (2 x 5 mL) and the organic phase was dried over Mg_2SO_4, filtered off and evaporated under reduced pressure to give the corresponding alkylated glycine.

General procedure for preparation of the corresponding *N*-trifluoroacetamide amido esters, 9-22

To a stirred mixture of alkylated glycine derivatives in THF (3 mL) was added an aqueous solution of citric acid 25% (2 mL). After 4 h the mixture was extracted with Et_2O (3 x 10 mL) and the resulting aqueous phase was basified with an aqueous saturated solution of K_2CO_3 (10 mL). Then extracted with EtOAc (3 x 15 mL), the organic phase was dried over Mg_2SO_4, filtered off and evaporated to give compounds the intermediate aminoacids. These aminoacids were dissolved in CH_2Cl_2 (5mL) and TFAA (1 mL) was added slowly at 0 ºC. The mixture was refluxed during 30 min and evaporated, to give the corresponding *N*-trifluoroacetamide amido esters. (

Supporting Information

In this document you can find the IR, ^{31}P NMR, ^{1}H NMR and ^{13}C NMR spectra of new dendrimers: **4-G$_1$** and **6-G$_1$a-d**. ^{31}P NMR, ^{1}H NMR and ^{13}C NMR spectra for previously reported **2-G$_1$** and **3-G$_1$** are gathered, and the experimental procedure for their obtaintion.^{1}H NMR spectra of used compounds **5b**, **5c** and **5d** previously reported are included. Tables showing yields and enantioselectivities of the reaction of **7** with **8**, optimizing solvents and bases are indicated. For compounds obtained in the catalytic experiments (**9**-**22**), ^{1}H and ^{13}C NMR spectra and chiral GC chromatograms are gathered (including the ones corresponding to the recycling process). This material is available free of charge via the Internet at http://pubs.acs.org.

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REFERENCES

[1] C. M. Starks, *J. Am. Chem. Soc.* **1971**, *93*, 195-199.
[2] Y. Sasson, R. Neumann in *Handbook in Phase Transfer Catalysis*, Blackie Academic & Professional, London, **1997**.
[3] For reviews on phase-transfer catalysis, see a) E. V. Dehmlow, S. S. Dehmlow in *Phase Transfer Catalysis*, 3rd ed., Wiley-VCH, Weinheim, **1993**; b) C. M. Starks, C. L. Liotta, M. Halpern in *Phase-Transfer Catalysis*, Chapman & Hall, New York, **1994**; c) Y. Sasson, R. Neumann in *Handbook of Phase-Transfer Catalysis*, Blackie Academic & Professional, London, **1997**.
[4] a) T. Ooi, K. Maruoka, *Angew. Chem. Int. Ed.* **2007**, *46*, 4222—4266; b) S. E. Denmark, N. D. Gould, L. M. Wolf, *J. Org. Chem.* **2011**, *76*, 4260-4336; c) S. Shirakawa, K. Maruoka, *Angew. Chem. Int. Ed.* **2013**, *52*, 4312-4348; d) M. J. O'Donnell, *Acc. Chem. Res.* **2004**, *37*, 506-517.
[5] a) A. Bhattacharya, U.-H. Dolling, E. J. J. Grabowski, S. Karady, K. M. Ryan, L. M. Weinstock, *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 476-477; b) J. Lu, L. Zhang, L. Liu, Y. Wang, *Chem. Lett.* **2007**, *36*, 1354-1355; c) S. E. Denmark, N. D. Gould, L. M. Wolf, *J. Org. Chem.* **2011**, *76*, 4260-4336; d) Y.-G. Wang, M. Ueda, X. Wang, Z. Han, K. Maruoka, *Tetrahedron* **2007**, *63*, 6042-6050; e) Y. Arakawa, N. Haraguchi, S. Itsuno, *Angew. Chem. Int. Ed.* **2008**, *47*, 8232-8235 ; f) P. Nun, V. Pérez, M. Calmés, J. Martinez, F. Lamaty, *Chem. Eur. J.* **2012**, *18*, 3773-3776.
[6] a) T. Perrard, J.-C. Plaquevent, J.-R. Desmurs, D. Hébrault, *Org. Lett.* **2000**, *2*, 2959-2962 ; b) T. Ooi, S. Fujioka, K. Maruoka *J. Am. Chem. Soc.* **2004**, *126*, 11790-11791 ; c) T. Ooi, D. Ohara, K. Fukumoto, K. Maruoka, *Org. Lett.* **2005**, *7*, 3195-3197; d) X. Wang, M. Kitamura, K. Maruoka, *J. Am. Chem. Soc.* **2007**, *129*, 1038-1039. e) H. Kawai, Y. Sugita, E. Tokunaga, H. Sato, M. Shiro, N. Shibata, *Chem. Commun.* **2012**, *48*, 3632-3634.
[7] a) T. Ooi, M. Taniguch, M. Kameda, K. Maruoka, *Angew. Chem. Int. Ed.* **2002**, *41*, 4542-4544; b) T. Ooi, M. Kameda, M. Taniguchi, K. Maruoka, *J. Am. Chem. Soc.* **2004**, *126*, 9685-9694; c) S. Shirakawa, K. Ota, S. J. Terao, K. Maruoka, *Org. Biomol. Chem.* **2012**, *10*, 5753-5755.
[8] C. D. Fiandra, L. Piras, F. Fini, P. Disetti, M. Moccia, M. F. A.Adamo, *Chem. Commun*. **2012**, *48*, 3863-3865.
[9] a) C. D. Fiandra, L. Piras, F. Fini, P. Disetti, M. Moccia, M. F. A. Adamo, *Chem. Commun*. **2012**, *48*, 3863-3865; b) J. Ye, Y. Wang, R. Liu, G. Zhang, Q. Zhang, J. Chen, X. Liang, *Chem. Commun.* **2003**, 2714-2715; c) M. -S. Yoo, D. - G. Kim, M. W. Ha, S. -S. Jew, H. -G. Park, B.-S. Jeong, *Tetrahedron Lett.* **2010**, *51*, 5601-5603.
[10] a) E. Murugan, A. Siva, *Synthesis* **2005**, 2022-2028; b) Y. Murakami, Y. Takeda, S. Minakata, *J. Org. Chem.* **2011**, *76*, 6277-6285.
[11] a) R. A. Bhunnoo, Y. Hu, D. I. Lainé, R. C. D. Brown, *Angew. Chem. Int. Ed.* **2002**, *41*, 3479-3480; b) J. Qi, A. B. Beeler, Q. Zhang, J. A. Porco, Jr., *J. Am. Chem. Soc.* **2010**, *132*, 13642-13644; c) P. Maity, S. D. Lepore, *Angew. Chem. Int. Ed.* **2011**, *50*, 8338-8341; d) E. Yamamoto, A. Nagai, A. Hamasaki, M. Tokunaga, *Chem. Eur. J.* **2011**, *17*, 7178-7182; e) L. Bernardi, E. Indrigo, S. Pollicino, A. Ricci, *Chem. Commun*. **2012**, *48*, 1428-1430.
[12] a) J. Jacques, A. Collet, and S. H. Wilen in *Enantiomers, Racemates and Resolutions*, John Wiley & Sons, Inc., New York, **1981**; b) D. Kozma in *CRC Handbook of Optical Resolutions via Diastereomeric Salts*, CRC Press, Boca Raton, Florida (US), **2002**.
[13] a) C. E. Song in *Cinchona Alkaloids in Synthesis and Catalysis: Ligands, Immobilization and Organocatalysis*, Wiley-VCH, Weinheim, **2009**; b) E. M. O. Yeboah, S. O. Yeboah, G. S. Singh, *Tetrahedron* **2011**, *67*, 1725-1762; c) D. Ager, E. M. Carreira, Y. Hisashi in *Comprehensive Chirality*, Elsevier, Oxford, **2012**, pp. 223-247; d) H. Li, Y. L. Chen Deng, A. L. Zhou in *Privileged Chiral Ligands and Catalysts*, Wiley-VCH, Weinheim, **2012**, pp. 361-408.
[14] S. S. Jew, H. Park, *Chem. Commun* **2009**, 7090-7103.
[15] M. J. O'Donnell, W. D. Bennett, S. Wu, *J. Am. Chem. Soc.* **1989**, *111*, 2353-2355; b) M. J. O'Donnell, S. Wu, J. C. Huffman, *Tetrahedron* **1994**, *50*, 4507-4518.
[16] a) E. J. Corey, F. Xu, M. C. Noe, *J. Am. Chem Soc.* **1997**, *119*, 12414-12415; b) E. J. Corey, Y. Bo, J. Busch-Petersen, *J. Am. Chem. Soc.* **1998**, *120*, 13000-13001.
[17] a) B. Lygo, P. G. Wainwright, *Tetrahedron Lett.* **1997**, 38, 8595-8598; b) B. Lygo, B. I. Andrews, *Acc. Chem. Res.* **2004**, *37*, 518-525.
[18] a) R. Chinchilla, P. Mazón, C. Nájera, *Tetrahedron: Asymmetry* **2000**, *11*, 3277-3281; b) R. Chinchilla, P. Mazón, C. Nájera, *Molecules* **2004**, *9*, 349-364; c) R. Chinchilla, P. Mazón, C. Nájera, *Adv. Synth. Catal*. **2004**, *346*, 1186-1194.
[19] B. Thierry, J. C. Plaquevent, D. Cahard, *Molec. Divers.* **2005**, *9*, 277-290.
[20] a) A. M. Caminade, C. O. Turrin, R. Laurent, A. Ouali, B. Delavaux-Nicot in *Dendrimers: Towards Catalytic, Material and Biomedical Uses*, Wiley-VCH, Chistester, **2011**; b) E. Badetti, A. M. Caminade, J. P. Majoral; M. Moreno-Mañas, R.M. Sebastián, *Langmuir* **2008**, *24*, 2090-2101; c) M. Koprowski, R. M. Sebastián, V. Maraval, M. Zablocka, V. Cadierno, B. Donnadieu, A. Igau, A. M. Caminade, J. P. Majoral, *Organometallics* **2002**, *21*, 4680-4687; d) G. Franc, E. Badetti, C. Dahayon, Y. Coppel, C. O. Turrin, J. P. Majoral, R. M. Sebastián, A. M. Caminade, *New. J. Chem.* **2010**, 24, 547-555; e) G. Franc, E. Badetti, V. Collière, J. P. Majoral, R.M. Sebastián, A. M. Caminade, *Nanoscale* **2009**, *1*, 233-237; f) M. Keller, V. Collière, O. Reiser, A. M. Caminade, J. P. Majoral, A. Ouali, *Angew. Chem. Int. Ed.* **2013**, *52*, 3626-3629; g) P. Neumann, H. Dib, A. M. Caminade, E. Hey-Hawkins, *Angew. Chem. Int. Ed.* **2015**, *54*, 311-314.
[20.5] A. M. Caminade, A. Ouali, R. Laurent, C.O. Turrin, J. P. Majoral, *Chem. Soc. Rev*. **2015**, *44*, 3890-3899.
[21] a) A. M. Caminade, A. Ouali, M. Keller, J. P. Majoral, *Chem. Soc. Rev.* **2012**, *41*, 4113-4125; b) M. Keller, A. Perrier, R. Linhardt, L. Travers, S. Wittmann, A. M. Caminade, J. M. Majoral, O. Reiser, A. Ouali, *Adv. Synth. Catal.* **2013**, *355*, 1748-1754.
[22] J. Rull, M. Casals, R. M. Sebastián, A. Vallribera, J. P. Majoral, A. M. Caminade, *ChemCatChem* **2015**, *7*, 2698-2704.
[23] a) G. Guillena, R. Kreiter, R. Van de Coevering, R. J. M. Klein Gebbink, G. Van Koten, P. Mazon, R. Chinchilla, C. Nájera, *Tetrahedron: Asymmetry* **2003**, *14*, 3705-3712; b) X. L. Liu, X. L. Bai, X. P. Qiu, L. X. Gao, *Chin. Chem. Lett.* **2005**, *16*, 975-978.
[24] a) B. Imperiali, S. L. Fisher, *J. Org. Chem.* **1992**, *57*, 757-759; b) B. Imperiali, T. J. Prins, S. L. Fisher, *J. Org. Chem.* **1993**, 58, 1613-1616; c) B. Lygo, B. I. Andrews, *Tetrahedron Lett.* **2003**, *44*, 4499-4502; d) B. Lygo, B. I. Andrews, D. Slack, *Tetrahedron Lett.* **2003**, *44*, 9039-9041.
[25] a) A. M. Caminade, A. Ouali, R. Laurent, C. O. Turrin, J. P. Majoral, *Coord. Chem. Rev.* **2016** *in press* doi:10.1016/j.ccr.2015.06.007; b) A. M. Caminade, A. Ouali, R. Laurent, C. O. Turrin, J. P. Majoral, *Chem. Soc. Rev.* **2015**, *44*, 3890-3899; c) A. M. Caminade, R. Laurent, A. Ouali, J. P. Majoral, *Inorg. Chim. Acta*. **2014**, *409*, 68-88; d) A. M. Caminade, J. P. Majoral, *New J. Chem.* **2013**, *37*, 3358-3373.
[26] P. Servin, R. Laurent, L. Gonsalvi, M. Tristany, M. Peruzzini, J. P. Majoral, A. M. Caminade, *Dalton Trans.* **2009**, 4432-4434.
[27] S. E. Denmark, R. C. Weintraub, *Heterocycles* **2011**, *82*, 1527-1540.
[28] H. G. Park, B. S. Jeong, M. S. Yoo, J. H. Lee, M. K. Park, Y. J. Lee, M. J. Kim, S. S. Jew, *Angew. Chem. Int. Ed.* **2002**, *41*, 3036-3038.
[29] R. M. Sebastián, G. Magro, A. M. Caminade, J. P. Majoral, *Tetrahedron* **2000**, *56*, 6269-6277.
[30] J. H. Lee, M. S. Yoo, J. H. Jung, S. S. Jew, H. G. Park, B. S. Jeong, *Tetrahedron* **2007**, *63*, 7906-7915.
[31] W. Oppolzer, R. Moretti, C. Zhou, *Helv. Chim. Acta* **1994**, *77*, 2363-2380.

[32] a) S. Jayaraman, D. Kumaraguru, J. B. Arockiam, S. Paulpandian, B. Rajendiran, S. Ayyanar, *Synlett* **2014**, *25*, 1685-1691; b) I. Busygin, V. Nieminen, A. Taskinen, J. Sinkkonen, E. Toukoniitty, R. Sillanpaa, D. Y. Murzin, R. Leino, *J. Org. Chem.* **2008**, *73*, 6559-6569.
[33] P. Nun, V. Pérez, M. Calmès, J. Martínez, F. Lamaty, *Chem. Eur. J.* **2012**, *18*, 3773-3779.