[12] *Comprehensive Organometallic Chemistry II, Vol. 6*, Pergamon, Oxford, **1995**, chap. 5, p. 109.

[13] The deprotonation[14] analogy can be used to consider the fragments {(cod)Pt} and {μ_3-S} isolobal with CH$_2$ and with CH$^-$. Since {Fe(CO)$_3$} is isolobal with CH$^+$, {Re(CO)$_3$} is isolobal with CH^{2+}. The thiocarbonylphosphorane can be split homolytically into S- and CPR$_3$, which is isolobal with CH. The planar ring can be considered as a (CH)$_5^+$ which is bonded through all five atoms to {Mn(CO)$_3$} (isolobal with CH^{2+}).

[14] R. Hoffmann, *Angew. Chem.* **1982**, *94*, 725–738; *Angew. Chem. Int. Ed. Engl.* **1982**,*21*, 711–724.

Highly Enantioselective and Practical Cinchona-Derived Phase-Transfer Catalysts for the Synthesis of α-Amino Acids**

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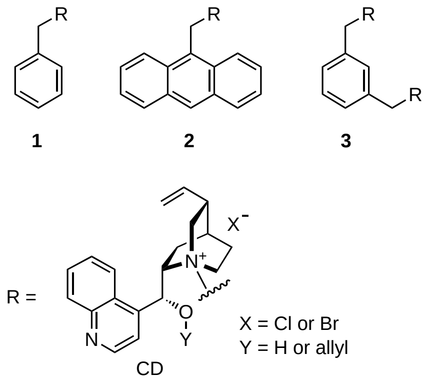
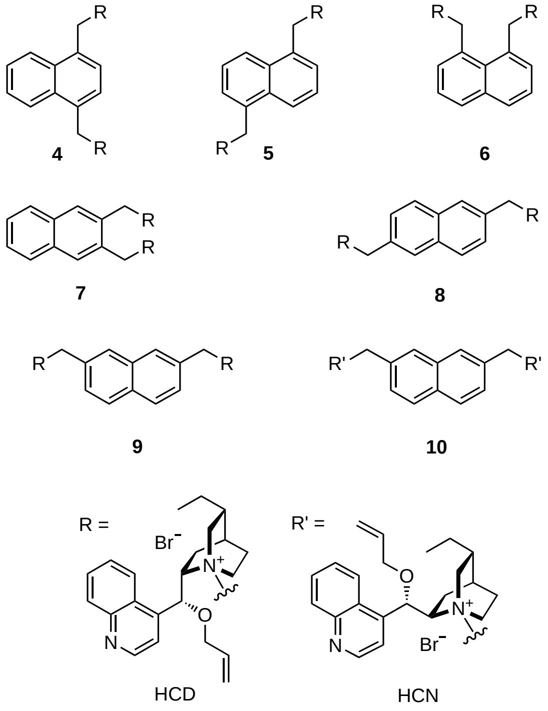
Phase-transfer catalysis (PTC) is one of the most useful methods for practical synthesis, because of its operational simplicity and mild reaction conditions, which enable this method to be applied to industrial processes.[1] Recently, PTC has been applied extensively to asymmetric synthesis by using chiral quaternary ammonium salts.[2] Chiral phase-transfer catalysts derived from the cinchona alkaloids have been developed and successfully applied to various useful organic reactions.[1d,e,3] Since the first cinchona alkaloid-type phase-transfer catalysts **1** were introduced by O'Donnell et al.,[4] more efficient catalysts **2** have been developed independently by Lygo et al.[5] and Corey et al.[6] by the introduction of the *N*-9-anthracenylmethyl group instead of the *N*-benzyl group in **1** (Scheme 1).



Scheme 1.

Based on the fact that the introduction of a bulky subunit at N1 of cinchona alkaloids leads to an enhancement of the stereoselectivity, we recently reported the efficient catalysts **3** by the formation of the *meta*-dimer, using benzene as a ligand (Scheme 1).[7] The enhancement of the stereoselectivity is a result of the screening effect between each cinchona unit (CD), which can make the substrate approach from only one direction. As part of our program to develop practical catalysts that can be used in industrial processes, we further investigated more optimal dimeric catalysts by modifying the ligand, that is, the benzene group in **3**. We report herein the preparation of new symmetrical dimeric cinchona-alkaloid-derived catalysts (Scheme 2), which have a naphthalene moiety as a ligand, and their application to the catalytic enantioselective phase-transfer alkylation of glycine derivative **11** (see Tables 1 and 2).



Scheme 2.

New dimeric quaternary ammonium salts **4**–**10** were prepared in two steps from (−)-hydrocinchonidine (for **4**–**9**) or (+)-hydrocinchonine (for **10**) and the corresponding bis(bromomethyl)naphthalenes, which can be easily prepared by the allylic bromination of the dimethylnaphthalenes. (−)-Hydrocinchonine or (+)-hydrocinchonine and the bis(bromomethyl)naphthalenes were stirred at 100 °C in EtOH/DMF/CHCl$_3$ (5:6:2) for 6 h, followed by O9-allylation with allyl bromide and aqueous KOH (50 %), to give the corresponding dimeric quaternary ammonium salts **4**–**10** in 90–95 % overall yields. The enantioselective efficiency of the naphthalene-based dimeric catalysts was evaluated by the enantioselective phase-transfer alkylation of **11**: the catalysts

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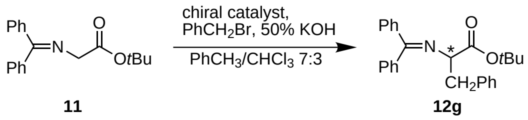
Supporting information for this article is available on the WWW under http://www.angewandte.org or from the author.

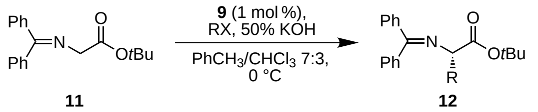
Table 1. Enantioselective phase-transfer-catalyzed benzylation of **11** catalyzed by **4**–**10**.[a]

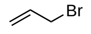
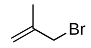
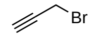
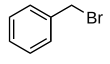
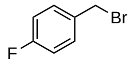
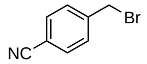
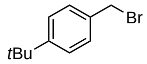
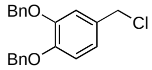
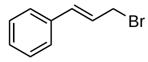
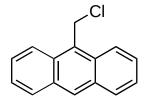


Entry	Catalyst	mol %	T [°C]	t [h]	Yield [%][b]	*ee* [%][c] (Config.)[d]
1	**4**	5	0	2	92	91 (*S*)
2	**5**	5	0	3	90	86 (*S*)
3	**6**	5	0	10	82	44 (*S*)
4	**7**	5	0	10	88	36 (*S*)
5	**8**	5	0	3	90	79 (*S*)
6	**9**	5	0	0.5	95	97 (*S*)
7	**9**	5	20	0.05	95	92 (*S*)
8	**9**	5	−20	6	93	98 (*S*)
9	**9**	5	−40	20	90	99 (*S*)
10	**10**	5	−40	20	88	96 (*R*)
11	**9**	1	0	10	95	97 (*S*)

[a] The reaction was carried out with benzyl bromide (5.0 equiv) and aqueous KOH (50%, 13.0 equiv) in toluene/chloroform (7:3) under the given conditions. [b] Yields of isolated products. [c] The enantiopurity was determined by HPLC analysis of the benzylated imine **12g** by using a chiral column (DAICEL Chiralcel OD) with hexanes/2-propanol (500:2.5) as solvent; in this case it was established by analysis of the racemate, of which the enantiomers were fully resolved. [d] The absolute configuration was determined by comparison of the HPLC retention time with that of an authentic sample, which was synthesized independently by reported procedures.[4–7]

Table 2. Catalytic enantioselective phase-transfer alkylation of **11** with various alkyl halides in the presence of **9** (1 mol %).[a]



Entry	RX	t [h]	Yield [%][b]	*ee* [%][c] (Config.)[d]
a	$(CH_3O)_2SO_2$	12	70	94 (*S*)
b	CH_3CH_2I	12	83	97 (*S*)
c	$CH_3(CH_2)_4CH_2I$	12	80	> 99 (*S*)
d		6	95	97 (*S*)
e		10	95	96 (*S*)
f		6	90	98 (*S*)
g		10	95	97 (*S*)
h		10	95	98 (*S*)
i		8	90	96 (*S*)
j		10	90	98 (*S*)
k		4	95	98 (*S*)
l		12	90	96 (*S*)
m		2	95	99 (*S*)

[a] The reaction was carried out with RX (5.0 equiv) and aqueous KOH (50%, 13.0 equiv) in the presence of **9** (1 mol%) in toluene/chloroform (7:3) at 0 °C. [b] Yields of isolated product. [c] Determined by chiral HPLC (see Supporting Information). [d] The absolute configuration was determined by comparison of the HPLC retention time with that of an authentic sample, which was independently synthesized by the reported procedure.[4–7]

(1–5 mol %) were mixed with ester **11**, benzyl bromide, and aqueous KOH (50 %) in toluene/chloroform (7:3) at −40 to 20 °C for 0.05–20 h.

As shown in Table 1, the 2,7-dimeric catalyst **9** showed the highest enantioselectivity (*S*, 97 % *ee*, 0 °C, 5 mol %) of the six (−)-hydrocinchonidine catalysts (**4**–**9**), whereas **6** and **7** gave poor selectivities (44 % *ee* and 36 % *ee*, respectively). The low selectivity might arise from the unfavorable conformation as a result of the severe steric repulsion between the two HCD units in **6** and **7**, which is in agreement with our previous study.[7a] Generally, a lower temperature results in higher enantioselectivities in the case of **9** (Table 1, entries 6–9). Notably, **9** can conserve its high catalytic efficiency in terms of both reactivity and enantioselectivity, even when present in a smaller quantity (1 mol %; Table 1, entry 10). Interestingly, the molecular structure of **9** markedly resembles that of **3**, except for the distance between the two cinchona alkaloid units. The naphthalene ligand of **9** is about 2.4 Å longer than the benzene ligand of **3**. The reason for the high enantioselectivity of **9** is not clear, but it is thought that the 2,7-naphthalene ligand confers a spatial benefit to form a more favorable conformation by decreasing the steric hindrance between the two HCD subunits relative to that in the 1,3-benzene ligand in **3**. The optimal ligand was adapted to prepare the dimeric (+)-hydrocinchonine catalyst **10** for the synthesis of the *R* isomer of **12**. As we expected, **10** also showed very high enantioselectivity (*R*, 96 % *ee*, −40 °C). Table 2 summarizes the results obtained for the alkylation of **11** with various alkyl halides in the presence of catalyst **9** (1 mol %) at 0 °C. The very high enantioselectivities (94–99 % *ee*) indicate that the catalyst **9** is a very efficient and practical phase-transfer catalyst for the enantioselective synthesis of natural and nonnatural *α*-amino acids.

In conclusion, we have developed a new class of naphthalene-based dimeric cinchona alkaloids as very efficient and practical phase-transfer catalysts (**4**–**10**). Among them, the 2,7-naphthalene-based dimeric catalysts **9** and **10** show excellent enantioselectivity in the alkylation of **11** to give (*S*)-**12** and (*R*)-**12**, respectively. The mild reaction conditions and the high catalytic efficiency could make **9** and **10** practical catalysts in the industrial synthetic process for natural and nonnatural chiral α-amino acids. Applications to various other types of phase-transfer catalytic reactions with **9** and **10** are currently being studied.

Experimental Section

For the detailed synthesis of **9** and its precursors, see Supporting Information.

General procedure (alkylation): Benzyl bromide (0.1 mL, 0.85 mmol) was added to a mixture of *N*-(diphenylmethylene)glycine *tert*-butyl ester (**11**; 50 mg, 0.17 mmol) and the chiral catalyst **9** (1.7 mg, 0.0017 mmol) in toluene/chloroform (7:3, 0.75 mL). The reaction mixture was then cooled (0 °C), aqueous KOH (50 %, 0.25 mL) was added, and the reaction mixture was stirred at 0 °C until the starting material had been consumed (10 h). The suspension was diluted with diethyl ether (20 mL), washed with water (2 × 5 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo. Purification of the residue by flash column chromatography on silica gel (hexanes/EtOAc 50:1) afforded the desired product **12g** (62 mg, 95 % yield) as a colorless oil. The enantioselectivity was determined by chiral HPLC analysis (DAICEL Chiralcel OD, hexane/2-propanol (500:2.5), flow rate 1.0 mL min^{-1}, 23 °C, λ 254 nm, retention times: *R* (minor) 12.2 min, *S* (major) 22.5 min, 97 % *ee*) The absolute configuration was determined by comparison of the HPLC retention time with the authentic sample synthesized by the reported procedure.[4–7]

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Facile Syntheses of Copper(I) Alkynyl Clusters Stabilized by Hexafluoroacetylacetonate (hfac) Ligands: The Structure of [Cu$_{26}$(hfac)$_{11}$(1-pentynyl)$_{15}$]**

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Whilst the copper(I) alkynyl complexes have been widely studied, for their potential as synthetic reagents,[1] their photophysical (luminescent) properties,[2–18] and the extraordinary variety of binding modes exhibited by alkynyl ligands,[14,18–24] only a few homometallic and homovalent Cu^I clusters with low nuclearities of 2,3,4, or 6 have been structurally characterized.[1,3–15,18–27] One of the problems in preparing and isolating high-nuclearity copper(I) complexes containing terminal alkynyl ligands is the propensity of such systems to aggregate indiscriminately to yield highly insoluble polymers or oligomers. One approach to overcoming this problem is to employ suitable "capping ligands" to protect the periphery of the cluster. If such ligands were available they could, in principle, be used to control the size and shape of clusters by varying the relative concentrations of capping and interstitial (alkynyl) ligands. To date, this synthetic strategy has been employed using predominantly neutral ligands, mostly phosphane-based (for example, PPh_3 and $Ph_2PCH_2PPh_2$),[2,3,5–10,12–15,18–22,24] and in a few cases mono-anionic ligands (for example, $2\text{-}Me_2NCH_2C_6H_4S^-$).[1,25]

Herein, we report a very convenient method for the synthesis of homovalent Cu^I clusters of the type [Cu$_{x+y}$(hfac)$_x$(RC≡C)$_y$] (hfac = hexafluoroacetylacetonate) and the structural characterization of the largest Cu^I cluster obtained to date, [Cu$_{26}$(hfac)$_{11}$(1-pentynyl)$_{15}$]. When hfacH is added dropwise to a suspension of Cu_2O and anhydrous $MgSO_4$ in excess alkyne (RC≡CH, R = $n\text{-}C_3H_7$, $n\text{-}C_4H_9$, $n\text{-}C_5H_{11}$, $n\text{-}C_6H_{13}$) an exothermic reaction is observed. After addition of *n*-hexane, filtration and washing, a lime-green solution is obtained which is presumed to contain mononuclear [Cu(hfac)(η^2_π-RC≡CH)] or similar species containing more than one neutral 1-alkyne ligand (Scheme 1).

Evaporation and subsequent heating (65 °C) in vacuo gives viscous red or orange oils or, more frequently, crystalline solids containing discrete organometallic complexes of the type [Cu$_{x+y}$(hfac)$_x$(RC≡C)$_y$], with yields in the range 20–50 %. In certain cases, partial aerial oxidation of such systems has generated new [Cu$_{x+y}$(hfac)$_x$(RC≡C)$_y$]-type clusters with higher nuclearities. Thus, when 1-pentyne was used as the reagent, [Cu$_{18}$(hfac)$_{10}$(pentynyl)$_8$] (orange solid) was isolated which, in

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