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Enantioselective Friedel–Crafts Alkylation of 4,7-Dihydroindoles with Enones Catalyzed by Primary–Secondary Diamines

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Over the past few years, a number of chiral organocatalysts have been developed for different asymmetric transformations.[1] Among them, chiral secondary amines are probably the most intensively used organocatalysts. In contrast, little progress has been made in the development of chiral primary amine catalysts, probably due to unfavorable imine–secondary enamine equilibria.[2] Nevertheless, the use of chiral primary amines as organocatalysts possesses particular charm because of their known occurrence in the catalytic sites of several enzymes, such as type I aldolases, dehydratases, and decarboxylases.[3] Recently, primary amine catalysts have emerged to be effective promoters for organic processes including Michael addition, aldol, α-aminations and cycloaddition reactions.[4] Despite the recent successful applications of primary amine catalysts (mainly derived from cinchona alkaloid or 1,2-diamino-cyclohexane) in the iminium catalysis of enones, few examples have been reported for the use of primary–secondary diamine catalysts in the Michael addition reactions of enones.[5]

2-Substituted indoles are potential intermediates for many alkaloids and pharmacologically important substances.[6] While the methods for the preparation of 3-substituted indoles are well established,[7] the development of novel and efficient catalytic asymmetric synthesis of 2-substituted indoles appears to be of great importance. 4,7-Dihydroindoles, due to their easy aromatization, are good intermediates to synthesize 2-substituted indoles. In this regard, the enantioselective Friedel–Crafts alkylation[8] of 4,7-dihydroindoles provides direct and useful access to such valuable scaffolds, and great efforts and progress have been made in this field.[9] However, to our knowledge, a general and highly enantioselective Friedel–Crafts alkylation of 4,7-dihydroindoles with enones is still lacking. Herein, we describe the development of a new chiral primary–secondary diamine catalyst derived from amino acid and its application in the asymmetric Friedel–Crafts alkylation of 4,7-dihydroindoles with α,β-unsaturated enones.

As part of our continuing interest in asymmetric organocatalytic Friedel–Crafts alkylation,[10] we recently found that chiral secondary amines were efficient catalysts for the asymmetric Friedel–Crafts reaction of 4,7-dihydroindoles with α,β-unsaturated aldehydes. We sought to extend this organocatalytic strategy to α,β-unsaturated ketones; however, our initial attempts led to unsatisfactory results probably due to poor generation of the corresponding iminium cations.[11] Considering the inherent problems of congested iminium ions from ketones, we questioned whether primary amines, in comparison with secondary amines, owing to their reduced steric requirements, might be more suitable for enone activation.

Based on the above consideration, an array of primary amines derived from amino acids were investigated in the asymmetric Friedel–Crafts alkylation of 4,7-dihydroindole (**1a**) with benzylideneacetone **2a** in toluene. When a primary amine catalyst **3a** or **3b** (see Figure 1) derived from L-phenylalanine was utilized, only low enantioselectivity was achieved (Table 1, entries 1 and 2). Fortunately, its monomethylated analogue **3c** catalyzed the reaction very efficiently to afford **4aa** in good yield and promising enantioselectivity (Table 1, entry 3). Encouraged by these findings, we investigated the effects of the substituent of the terminal amino group on the catalytic activity of **3**. We found that the length of the alkyl chain influenced the catalytic activity of **3** and the *n*-propylated catalyst **3e** gave the best result (Table 1, entry 5). To our surprise, the primary–tertiary diamine catalysts **3g** or **3h**, a general catalyst for the Michael

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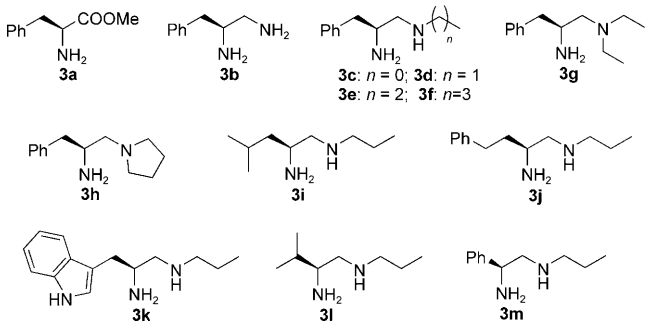


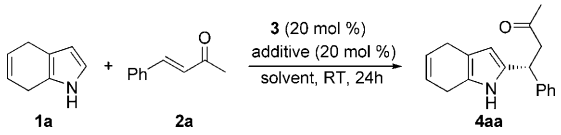
Figure 1. Structures of various primary amine catalysts.

addition of α,β-unsaturated aldehyde, was not active in the present reaction (Table 1, entries 7 and 8). Moreover, variation of the amino acid side chain yielded the optimum catalyst **3i** derived from leucine, which provided the desired product **4aa** with 90% *ee* (Table 1, entry 9).

The acid co-catalyst also had a great effect on the reaction. Almost no reaction occurred when no acid was added (Table 1, entry 14). The use of two rather than one equivalents of acid apparently lowered the enantioselectivity (Table 1, entries 9 vs 15). The general tendency was that salts of amine **3** with stronger acids were more reactive and gave better enantioselectivity. Trifluoroacetic acid turned out to be the best co-catalyst in terms of yield and enantioselectivity (Table 1, entry 9). We also investigated a variety of solvents, and $CHCl_3$ turned out to be optimal (Table 1, entry 22). When the reaction temperature was lowered to 0°C, the enantioselectivity increased to 94% *ee* to isolate **4aa** in 86% yield, although the reaction time had to be extended to 48 h (Table 1, entry 24). Further decrease of the temperature to −60°C did not have any positive effects on the reaction results and the *ee* values decreased to 28% (Table 1, entry 25).

Having established optimal reaction conditions, we next examined the scope and limitations of the method with regard to the enone and 4,7-dihydroindole substrates. In all cases, the reaction proceeded smoothly to furnish the desired product **4** in high yields and excellent enantioselectivities. For enones carrying both aromatic and aliphatic substituents, almost optically pure products were obtained in excellent yields, irrespective of steric and electronic demands of the β-olefin substituent (Table 2, entries 1–10). No decrease in yield and *ee* value was observed for the slightly sterically hindered enone **2k** (Table 2, entry 11). Interestingly, chalcone **2l**, a particularly challenging class of substrates for iminium catalysis, afforded the expected products in high optical purity (Table 2, entry 12). Unfortunately, when cyclic enone **2m** was used, only a moderate *ee* was obtained

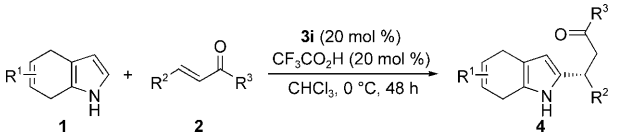
Table 1. Catalyst screening and reaction optimization.[a]



Entry	Catalyst	Solvent	Additive	Yield [%][b]	*ee* [%][c]
1	**3a**	toluene	CF_3CO_2H	39	8
2	**3b**	toluene	CF_3CO_2H	63	17
3	**3c**	toluene	CF_3CO_2H	71	79
4	**3d**	toluene	CF_3CO_2H	79	81
5	**3e**	toluene	CF_3CO_2H	83	82
6	**3f**	toluene	CF_3CO_2H	81	79
7	**3g**	toluene	CF_3CO_2H	65	62
8	**3h**	toluene	CF_3CO_2H	54	61
9	**3i**	toluene	CF_3CO_2H	86	90
10	**3j**	toluene	CF_3CO_2H	88	85
11	**3k**	toluene	CF_3CO_2H	67	84
12	**3l**	toluene	CF_3CO_2H	73	75
13	**3m**	toluene	CF_3CO_2H	65	69
14	**3i**	toluene	none	<10	n.d.[d]
15	**3i**	toluene	CF_3CO_2H[e]	91	74
16	**3i**	toluene	$PhCO_2H$	70	76
17	**3i**	toluene	*p*-TSA	78	87
18	**3i**	toluene	D-CSA	83	88
19	**3i**	THF	CF_3CO_2H	63	70
20	**3i**	ether	CF_3CO_2H	84	81
21	**3i**	CH_2Cl_2	CF_3CO_2H	81	90
22	**3i**	$CHCl_3$	CF_3CO_2H	90	92
23	**3i**	MTBE	CF_3CO_2H	80	88
24[f]	**3i**	$CHCl_3$	CF_3CO_2H	86	94
25[g]	**3i**	$CHCl_3$	CF_3CO_2H	59	28

[a] Unless otherwise specified, the reaction was carried out with **1a** (0.30 mmol) and **2a** (0.36 mmol) in the presence of an organocatalyst **3** (0.06 mmol), additive (0.06 mmol), and solvent (1.0 mL) for 24 h. [b] Isolated yield. [c] Determined by chiral HPLC on a Chiralpak AD column. [d] Not determined. [e] 40 mol% CF_3CO_2H was used. [f] The reaction was performed at 0°C for 48 h. [g] The reaction was performed at −60°C for 72 h.

Table 2. Scope of Friedel–Crafts alkylation catalyzed by primary amine catalyst **3i**.[a]

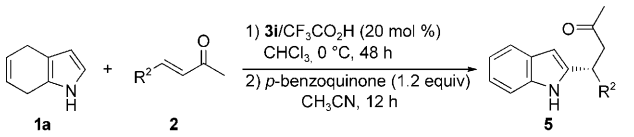


Entry	R^1	R^2	R^3	**4**, Yield [%][b]	*ee* [%][c]
1	H, **1a**	Ph	Me, **2a**	**4aa**, 86	94
2	H, **1a**	2-MeOPh	Me, **2b**	**4ab**, 69	95
3	H, **1a**	2-ClPh	Me, **2c**	**4ac**, 84	95
4	H, **1a**	3-MeOPh	Me, **2d**	**4ad**, 87	94
5	H, **1a**	3-ClPh	Me, **2e**	**4ae**, 93	92
6	H, **1a**	4-FPh	Me, **2f**	**4af**, 89	96
7	H, **1a**	4-ClPh	Me, **2g**	**4ag**, 91	97
8	H, **1a**	4-BrPh	Me, **2h**	**4ah**, 91	95
9	H, **1a**	n-C_3H_7	Me, **2i**	**4ai**, 83	91
10	H, **1a**	n-C_5H_{11}	Me, **2j**	**4aj**, 78	90
11	H, **1a**	Ph	Et, **2k**	**4ak**, 81	96
12	H, **1a**	Ph	Ph, **2l**	**4al**, 75	85
13	H, **1a**	$(CH_2)_3$, **2m**		**4am**, 97	66
14	5-MeO, **1b**	Ph	Me, **2a**	**4ba**, 82	93
15	5-MeO, **1b**	4-BrPh	Me, **2h**	**4bh**, 85	95
16	5-F, **1c**	Ph	Me, **2a**	**4ca**, 80	96
17	1-Me, **1d**	Ph	Me, **2a**	<10	n.d.[d]

[a] Unless otherwise specified, the reactions were carried out on a 0.30 mmol scale of **2** with 1.2 equiv of **1** in $CHCl_3$ at 0°C for 48 h in the presence of 20 mol% of **3i** and CF_3CO_2H. [b] Isolated yield. [c] For analysis of the *ee* values of the products, see the Supporting Information. [d] Not determined.

(Table 2, entry 13). Finally, substituted 4,7-dihydroindole **1b** and **1c** were tested, also with good results (Table 2, entries 14–16). However, as a limitation of the approach, the substitution on the 4,7-dihydroindolic nitrogen had a detrimental effect on the reactivity (Table 2, entry 17). This phenomenon has been observed in other organocatalytic Friedel–Crafts alkylations of indoles, which are assumed to proceed via a dual activation mechanism.[7j,10a,12]

To demonstrate the suitability of the current methodology for the synthesis of 2-functionalized indoles, the oxidation of 2-substituted 4,7-dihydroindoles was tested. To our delight the corresponding 2-substituted indole derivatives were obtained smoothly in good overall yields without any loss of enantioselectivies in all cases (Scheme 1).

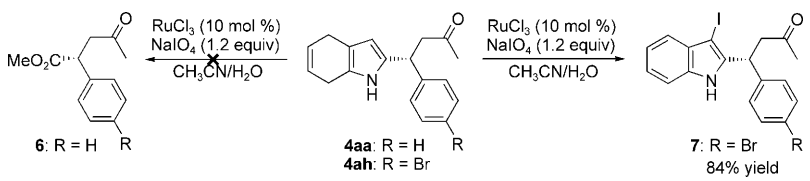


Scheme 1. Synthesis of 2-functionalized indoles.

To determine the absolute configuration of the product, we tried to oxidize **4aa** to the literature-known compound **6** in analogy to the oxidative cleavage of pyrroles upon treatment with $NaIO_4$ in the presence of $RuCl_3$.[13] Unfortunately, the oxidative cleavage product **6** was not observed. Instead, the oxidation–iodination product **7**, which is beneficial for numerous further transformations at C3 of indole,[14] was formed in high yield in one step from **4ah** (Scheme 2). Finally, suitable crystals of compound **7** which enabled assignment of the absolute configuration were obtained, and a single-crystal analysis revealed the configuration to be *R* (Figure 2).[15]

With regards to the mechanism, we envisioned that catalyst **3i** would act in a bifunctional fashion (Figure 3). The primary amine moiety activates the enone **2** via the formation of an iminum A, while the secondary amine may interact with the N-H of 4,7-dihydroindole through a weak hydrogen bond to direct the attack of 4,7-dihydroindole toward one enantioface of the double bond. The fact that *N*-methyl-4,7-dihydroindole gives no reaction supports the necessary existence of the hydrogen bond between the N-H atom and the secondary amine.

In summary, a primary–secondary diamine catalyst has been successfully applied in the Friedel–Crafts alkylation of



Scheme 2. Conversion of **4ah** to **7**.

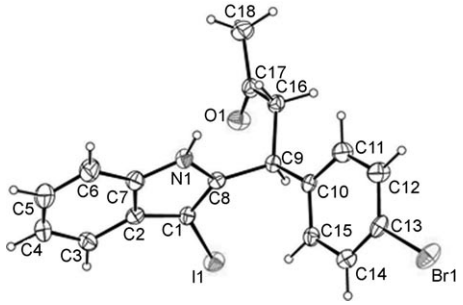


Figure 2. X-ray structure of (*R*)-**7**.

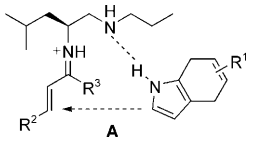


Figure 3. Pretransition state A.

4,7-dihydroindoles with α,β-unsaturated enones in high yields and excellent enantioselectivies. The corresponding 4,7-dihydroindole products could be subsequently transformed to 2-functionalized indoles by the oxidation of *p*-benzoquinone without any loss of enantioselectivies. Further application of the current methodology and study of the reaction mechanism are ongoing in our laboratory.

Experimental Section

General procedure for the catalytic asymmetric Friedel–Crafts reaction: To a mixture of enone **2a** (0.30 mmol), catalyst **3i** (0.06 mmol) and TFA (0.06 mmol) in $CHCl_3$ (1.0 mL) was added 4,7-dihydroindole (**1a**; 0.36 mmol) at room temperature. After 48 h of stirring, the reaction mixture was concentrated, and the residue was purified by flash chromatography (petroleum ether/ethyl acetate 6:1) to afford product **4aa**.

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Keywords: conjugate addition · enantioselectivity · enones · Friedel–Crafts reaction · organocatalysis

[1] For selected reviews of organocatalysis, see: a) P. I. Dalko, L. Moisan, *Angew. Chem.* **2004**, *116*, 5248; *Angew. Chem. Int. Ed.* **2004**, *43*, 5138; b) special issue on organocatalysis: *Acc. Chem. Res.* **2004**, *37*, Issue 8; c) J. Seayad, B. List, *Org. Biomol. Chem.* **2005**, *3*, 719; d) B. List, J. W. Yang, *Science* **2006**, *313*, 1584; e) B. List, *Chem. Commun.* **2006**, 819; f) M. J. Gaunt, C. C. C. Johansson, A. McNally, N. T. Vo, *Drug*

Discov. Today **2007**, *12*, 8; g) special issue on organocatalysis: *Chem. Rev.* **2007**, *107*, Issue 12; h) P. I. Dalko, *Enantioselective Organocatalysis*, Wiley-VCH, Weinheim, **2007**; i) A. Dondoni, A. Massi, *Angew. Chem.* **2008**, *120*, 4716; *Angew. Chem. Int. Ed.* **2008**, *47*, 4638.

[2] a) M. Yamaguchi, T. Shiraishi, M. Hirama, *J. Org. Chem.* **1996**, *61*, 3520; b) S. Hanessian, V. Pham, *Org. Lett.* **2000**, *2*, 2975; c) A. B. Northrup, D. W. C. MacMillan, *J. Am. Chem. Soc.* **2002**, *124*, 2458; d) N. Halland, P. S. Aburel, K. A. Jørgensen, *Angew. Chem.* **2003**, *115*, 685; *Angew. Chem. Int. Ed.* **2003**, *42*, 661; e) N. Halland, T. Hansen, K. A. Jørgensen, *Angew. Chem.* **2003**, *115*, 5105; *Angew. Chem. Int. Ed.* **2003**, *42*, 4955; f) F. Tanaka, R. Thayumanavan, N. Mase, C. F. Barbas III, *Tetrahedron Lett.* **2004**, *45*, 325; g) S. Pizzarello, A. L. Weber, *Science* **2004**, *303*, 1151; h) N. Halland, P. S. Aburel, K. A. Jørgensen, *Angew. Chem.* **2004**, *116*, 1292; *Angew. Chem. Int. Ed.* **2004**, *43*, 1272; i) A. Córdova, W. Zou, I. Ibrahem, E. Reyes, M. Engqvist, W.-W. Liao, *Chem. Commun.* **2005**, 3586; j) I. Ibrahem, W. Zou, M. Engqvist, Y. Xu, A. Córdova, *Chem. Eur. J.* **2005**, *11*, 7024; k) A. Prieto, N. Halland, K. A. Jørgensen, *Org. Lett.* **2005**, *7*, 3897; l) K. R. Knudsen, C. E. T. Mitchell, S. V. Ley, *Chem. Commun.* **2006**, 66; m) Y. Xu, A. Córdova, *Chem. Commun.* **2006**, 460.

[3] D. J. Hupe in *New Comprehensive Biochemistry, Vol. 6* (Ed.: M. I. Page), Elsevier, Amsterdam, **1984**, pp. 271–301.

[4] a) J. Liu, Z. Yang, Z. Wang, F. Wang, X. Chen, X. Liu, X. Feng, Z. Su, C. Hu, *J. Am. Chem. Soc.* **2008**, *130*, 5654; b) S. Luo, H. Xu, L. Chen, J.-P. Cheng, *Org. Lett.* **2008**, *10*, 1775; c) S. Luo, H. Xu, L. Zhang, J. Li, J.-P. Cheng, *Org. Lett.* **2008**, *10*, 653; d) S. Luo, J. Li, L. Zhang, H. Xu, J.-P. Cheng, *Chem. Eur. J.* **2008**, *14*, 1273; e) K. H. Kim, S. Lee, D.-W. Lee, D.-H. Ko, D.-C. Ha, *Tetrahedron Lett.* **2005**, *46*, 5991; f) S. S. V. Ramasastry, H. Zhang, F. Tanaka, C. F. Barbas III, *J. Am. Chem. Soc.* **2007**, *129*, 288; g) P. Ricci, A. Carlone, G. Bartoli, M. Bosco, L. Sambri, P. Melchiorre, *Adv. Synth. Catal.* **2008**, *350*, 49; h) C. M. Reisinger, X. Wang, B. List, *Angew. Chem.* **2008**, *120*, 8232; *Angew. Chem. Int. Ed.* **2008**, *47*, 8112; i) T.-R. Kang, J.-W. Xie, W. Du, X. Feng, Y.-C. Chen, *Org. Biomol. Chem.* **2008**, *6*, 2673; j) B. Tan, Z. Shi, P. J. Chua, G. Zhong, *Org. Lett.* **2008**, *10*, 3425; k) S. H. McCooey, S. J. Connon, *Org. Lett.* **2007**, *9*, 599; l) J.-W. Xie, L. Yue, W. Chen, W. Du, J. Zhu, J.-G. Deng, Y.-C. Chen, *Org. Lett.* **2007**, *9*, 413; m) T.-Y. Liu, H.-L. Cui, Y. Zhang, K. Jiang, W. Du, Z.-Q. He, Y.-C. Chen, *Org. Lett.* **2007**, *9*, 3671; n) S. Luo, H. Xu, J. Li, L. Zhang, J.-P. Cheng, *J. Am. Chem. Soc.* **2007**, *129*, 3074; o) W. Chen, W. Du, Y.-Z. Duan, Y. Wu, S.-Y. Yang, Y.-C. Chen, *Angew. Chem.* **2007**, *119*, 7811; *Angew. Chem. Int. Ed.* **2007**, *46*, 7667; p) X. Wang, C. M. Reisinger, B. List, *J. Am. Chem. Soc.* **2008**, *130*, 6070; q) R. P. Singh, K. Bartelson, Y. Wang, H. Su, X. Lu, L. Deng, *J. Am. Chem. Soc.* **2008**, *130*, 2422; r) J.-W. Xie, W. Chen, R. Li, M. Zeng, W. Du, L. Yue, Y.-C. Chen, Y. Wu, J. Zhu, J.-G. Deng, *Angew. Chem.* **2007**, *119*, 393; *Angew. Chem. Int. Ed.* **2007**, *46*, 389; s) X. Lu, Y. Liu, B. Sun, B. Cindric, L. Deng, *J. Am. Chem. Soc.* **2008**, *130*, 8134; for some leading reviews, see: t) L.-W. Xu, Y.-X. Lu, *Org. Biomol. Chem.* **2008**, *6*, 2047; u) Y.-C. Chen, *Synlett* **2008**, 1919.

[5] Y.-Q. Yang, G. Zhao, *Chem. Eur. J.* **2008**, *14*, 10888.

[6] a) M. E. Kuehne, D. E. Podhorez, T. Mulamba, W. G. Bornmann, *J. Org. Chem.* **1987**, *52*, 347; b) R. K. Brown in *Heterocyclic Compounds, Vol. 25* (Ed.: W. J. Houlihan), Wiley-Interscience, New York, **1972**; c) R. J. Sundberg in *The Chemistry of Indoles* (Ed.: A. T. Blomquist), Academic Press, New York, **1970**; d) P. Leon, C. Garbay-Jaureguiberry, M. C. Barsi, J. B. LePecq, B. P. Roques, *J. Med. Chem.* **1987**, *30*, 2074; e) C. Hashimoto, H.-P. Husson, *Tetrahedron Lett.* **1988**, *29*, 4563; f) M. Laronze, J. Sapi, *Tetrahedron Lett.* **2002**, *43*, 7925.

[7] a) J. F. Austin, D. W. C. MacMillan, *J. Am. Chem. Soc.* **2002**, *124*, 1172; b) J. Zhou, Y. Tang, *J. Am. Chem. Soc.* **2002**, *124*, 9030; c) D. A. Evans, K. A. Scheidt, K. R. Fandrick, H. W. Lam, J. Wu, *J. Am. Chem. Soc.* **2003**, *125*, 10780; d) C. Palomo, M. Oiarbide, B. G. Kardak, J. M. García, A. Linden, *J. Am. Chem. Soc.* **2005**, *127*, 4154; e) D. A. Evans, K. R. Fandrick, H.-J. Song, *J. Am. Chem. Soc.* **2005**, *127*, 8942; f) Y.-X. Jia, J.-H. Xie, H.-F. Duan, L.-X. Wang, Q.-L. Zhou, *Org. Lett.* **2006**, *8*, 1621; g) S.-F. Lu, D.-M. Du, J. Xu, *Org. Lett.* **2006**, *8*, 2115; h) H. Li, Y.-Q. Wang, L. Deng, *Org. Lett.* **2006**, *8*, 4063; i) W. Zhou, L.-W. Xu, L. Li, L. Yang, C.-G. Xia, *Eur. J. Org. Chem.* **2006**, 5225; j) G. Bartoli, M. Bosco, A. Carlone, F. Pesciaioli, L. Sambri, P. Melchiorre, *Org. Lett.* **2007**, *9*, 1403; k) C.-F. Li, H. Liu, J. Liao, Y.-J. Cao, X.-P. Liu, W.-J. Xiao, *Org. Lett.* **2007**, *9*, 1847; l) H. Yang, Y.-T. Hong, S. Kim, *Org. Lett.* **2007**, *9*, 2281; m) G. Blay, I. Fernández, J. R. Pedro, C. Vila, *Org. Lett.* **2007**, *9*, 2601; n) H.-M. Dong, H.-H. Lu, L.-Q. Lu, C.-B. Chen; W.-J. Xiao, *Adv. Synth. Catal.* **2007**, *349*, 1597; W.-J. Xiao, *Adv. Synth. Catal.* **2007**, *349*, 1597; o) M. Rueping, B. J. Nachtsheim, S. A. Moreth, M. Bolte, *Angew. Chem.* **2008**, *120*, 603; *Angew. Chem. Int. Ed.* **2008**, *47*, 593; p) J. Itoh, K. Fuchibe, T. Akiyama, *Angew. Chem.* **2008**, *120*, 4080; *Angew. Chem. Int. Ed.* **2008**, *47*, 4016; q) H.-Y. Tang, A.-D. Lu, Z.-H. Zhou, G.-F. Zhao, L.-N. He, C.-C. Tang, *Eur. J. Org. Chem.* **2008**, 1406.

[8] For recent reviews of Friedel–Crafts alkylation reaction, see: a) M. Bandini, A. Melloni, A. Umani-Ronchi, *Angew. Chem.* **2004**, *116*, 560; *Angew. Chem. Int. Ed.* **2004**, *43*, 550; b) K. A. Jørgensen, *Synthesis* **2003**, 1117; c) Y. Wang, K.-L. Ding, *Chin. J. Org. Chem.* **2001**, *21*, 763; d) T. B. Poulsen, K. A. Jørgensen, *Chem. Rev.* **2008**, *108*, 2903; e) M. Bandini, A. Melloni, S. Tommasi, A. Umani-Ronchi, *Synlett* **2005**, 1199; f) M. Bandini, A. Umani-Ronchi, *Catalytic Asymmetric Friedel–Crafts Alkylations*, Wiley-VCH, Weinheim, **2009**.

[9] a) H. Çavdar, N. Saraçoğlu, *Tetrahedron* **2005**, *61*, 2401; b) H. Çavdar, N. Saraçoğlu, *J. Org. Chem.* **2006**, *71*, 7793; c) D. A. Evans, K. R. Fandrick, *Org. Lett.* **2006**, *8*, 2249; d) D. A. Evans, K. R. Fandrick, H.-J. Song, K. A. Scheidt, R. Xu, *J. Am. Chem. Soc.* **2007**, *129*, 10029; e) G. Blay, I. Fernández, J. R. Pedro, C. Vila, *Tetrahedron Lett.* **2007**, *48*, 6731; f) G. Blay, I. Fernández, A. Monleón, J. R. Pedro, C. Vila, *Org. Lett.* **2009**, *11*, 441; g) Q. Kang, X.-J. Zheng, S.-L. You, *Chem. Eur. J.* **2008**, *14*, 3539; h) M. Zeng, Q. Kang, Q.-L. He, S.-L. You, *Adv. Synth. Catal.* **2008**, *350*, 2169; i) Y.-F. Sheng, G.-Q. Li, Q. Kang, A.-J. Zhang, S.-L. You, *Chem. Eur. J.* **2009**, *15*, 3351.

[10] a) L. Hong, L, Wang, C. Chen, B. Zhang, R. Wang, *Adv. Synth. Catal.* **2009**, *351*, 772; b) L. Hong, C. Liu, W. Sun, L. Wang, K. Wong, R. Wang, *Org. Lett.* **2009**, *11*, 2177.

[11] In our initial experiments, the use of diphenylprolinol ether promoted the reaction in poor yield (<10% yield).

[12] a) B. Török, M. Abid, G. London, J. Esquibel, M. Török, S. C. Mhadgut, P. Yan and G. K. S. Prakash, *Angew. Chem.* **2005**, *117*, 3146; *Angew. Chem. Int. Ed.* **2005**, *44*, 3086; b) H. Li, Y. Q. Wang, L. Deng, *Org. Lett.* **2006**, *8*, 4063; c) Y.-X. Jia, J. Zhong, S.-F. Zhu, C.-M. Zhang, Q.-L. Zhou, *Angew. Chem.* **2007**, *119*, 5661; *Angew. Chem. Int. Ed.* **2007**, *46*, 5565.

[13] a) B. M. Trost, C. Müller, *J. Am. Chem. Soc.* **2008**, *130*, 2438; b) G. Blay, I. Fernández, A. Monleón, J. R. Pedro, C. Vila, *Org. Lett.* **2009**, *11*, 441.

[14] a) N. A. Bumagin, V. V. Bykov, *Tetrahedron* **1997**, *53*, 14437; b) T. B. Ayed, J. Villiéras, H. Amri, *Tetrahedron* **2000**, *56*, 805; c) M. C. Walczak, R. S. Coleman, *Org. Lett.* **2005**, *7*, 2289; d) Z. Lu, S. Ma, *J. Org. Chem.* **2006**, *71*, 2655.

[15] CCDC-734380 (**7**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

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