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Reductive Homocoupling of Organohalides *via* the Direct Use of Nickel(II) Chloride and Samarium Metal

Yongjun Liu,*[a] Shuhuan Xiao,[a] Yan Qi,[a] and Feng Du[a]

Dedication ((optional))

Abstract: Catalyzed by $NiCl_2$ (5 mol %) directly, the homocoupling of organohalides was efficiently accomplished by the promotion of samarium metal in the presence of HMPA. Various organohalides (benzyl, aryl, heterocyclic, alkenyl and alkyl halides), α-haloacetophenones, and phenyl organosulfonates were compatible with the conditions to afford coupling products with high efficiency. Excellent chemoselectivity was exhibited between halides and other groups, such as –COOH, -NO_2, -X (inerter halogen), heterocyclic ring, ester, and ketone groups. The particular stereoselectivity implied that the reaction mechanism might involve an organosamarium species.

Introduction

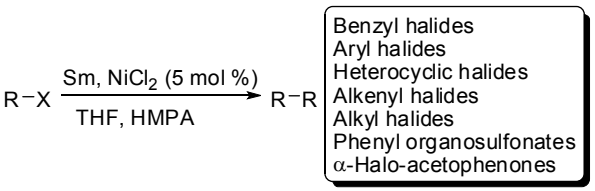
Reactions leading to C-C bond formation are considered the cornerstones in organic synthesis, among which the coupling reactions employing organohalides are often the key steps in a wide range of organic processes.[1-5] Transition metals have been demonstrated as the most powerful catalysts for these transformations,[1a-e,2-5] such as copper,[2a] rhodium,[5a] iron,[5b] cobalt,[2b-c,5c] palladium,[2d-e] and nickel.[3-4] Due to the versatile catalytic activities and ready availability, nickel-catalyzed couplings played an extremely important role in the development of the methodologies in recent years..[1a-c,3-4]

Compared with nickel-catalyzed cross-couplings of organohalides which often involve stepwise reactions,[3] the one-step reductive homocouplings are usually limited due to the varied reactivity and the chemoselectivity of organohalides.[1c,4-5] In most cases complicated ligands or particular Ni-complexes are crucial to the couplings, such as 2,2':6',2''-terpyridine,[4a] diphenylphosphinoferrocene,[4b] POCOP-nickel pincer complexes,[4c] 4,4',4''-*tri*-*t*-butyl-2,2':6',2''-terpyridine,[4d] and 1,3-bis(diphenylphosphino)propane dichloronickel.[4e] The coupling efficiency usually depends upon the catalytic system, i.e., particular ligands or complexes of nickel salts, rather than the reductive agents which are employed to ensure the success of catalytic cycle, such as Zn,[4a-d] Mn,[4e,5c] NH_2NH_2,[4j] R_2Zn,[5a] and BuLi.[4f,5b] The types of the bond formation also influence the coupling considerably, commonly involving the bond formation of Csp^2-Csp^2 (alkenylhalides[4b] or arylhalides[4f,5b]) and Csp^3-Csp^3 (benzylhalides[4c,4j,5a,5c] or alkylhalides[4a,g-i,5c]). It is a challenge to explore a widely applicable homocoupling protocol for organohalides as versatile as possible, and to simplify the catalytic system, especially the direct use of $NiCl_2$.

Samarium reagents have been extensively exploited in synthetic community[6-9] since its initial introduction to organic synthesis in 1977 by Kagan.[6] In contrast to the widespread applications of SmI_2,[7-8] however, the direct use of samarium metal draws relatively less attention.[9] Remarkably, the direct use of metallic samarium showed certain advantages over SmI_2, such as more practical and electron-economical.[9] On the other hand, the incorporation of nickel salts into reducing agents for the achievement of specific purposes is impressive.[3-4] By virtue of the strong reductive coupling ability of samarium, we assume samarium metal incorporated with nickel salt should exhibit exceptional reactivity upon some classical reactions. It is believed that SmI_2 is capable of readily reducing Ni(II) to Ni(0), and the addition of catalytic amounts of Ni(II) salts was believed to provide enhanced reactivity and selectivity of SmI_2.[10a]

Results and Discussion

The Sm/$NiCl_2$ combination was applied in the homocoupling of organohalides herein, and thus provided a versatile homocoupling of organohalides in good efficiency (Scheme 1).



Scheme 1. The Homocoupling of various Organohalides.

Initially, benzyl bromide was chosen as the model substrate to investigate the feasibility of the reaction under various conditions, and the results are summarized in Table 1. First of all, a control with Ni salt was performed (entries 1-6). The presence of $NiCl_2$ proved to be critical to the coupling (Table 1, entry 1), and 5 mol % amount was suitable to complete the reaction (entries 2-5). Nevertheless, hexahydrated nickel chloride impeded the coupling reaction significantly (entry 6). Among the reducing agents, samarium metal exhibited the most powerful reactivity (compared with entries 7-11). It should be pointed out that only a complex mixture was afforded when SmI_2 was used instead of

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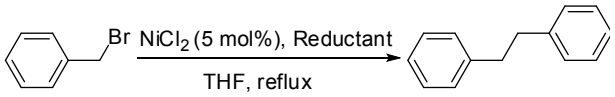
samarium metal (entry 7), which may also be regarded as a $SmI_2/Ni^{(0)}$ reaction system considering the catalytic amount of $NiCl_2$.[10a] However, to ensure smooth reaction, certain additives were required, among which the use of HMPA proved necessary in establishing and improving the reactions (compared with entries 12-17). As it is known, the extraordinary effects of HMPA may be attributed to its particular interaction with samarium.[10b-f] It is interesting that no remarkable suppression of the coupling was observed when the coupling was carried out in the presence of 2,6-*di-tert*-butyl-4-methylphenol (entry 18), which may be useful to the further investigation of the mechanism.

Table 1. Optimization of the Reaction Conditions.



Entry[a]	Reductant	$NiCl_2$ (mol%)	Additive	Time (h)	Yield (%)[b]
1	Sm	0	HMPA	12	--[c,d]
2	Sm	50	HMPA	0.5	95
3	Sm	100	HMPA	3	93
4	Sm	5	HMPA	8	93
5	Sm	1	HMPA	24	74
6	Sm	10[e]	HMPA	24	31
7	SmI_2	5	HMPA	0.5	--[f]
8	Mg	5	HMPA	4	--[f]
9	Zn	5	HMPA	24	--[f]
10	Mn	5	HMPA	24	--[f]
11	Fe	5	HMPA	24	--[d]
12	Sm	10		12	9
13	Sm	5	TMSCl	8	46
14	Sm	5	KI	12	61
15	Sm	5	I_2[g]	12	54
16	Sm	5	1,10-phen	12	71
17	Sm	5	bipy	12	67
18	Sm	5	HMPA/BHT[h]	12	82

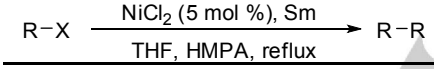
[a] Table Footnote. [b] Isolated yields. [c] Without the presence of $NiCl_2$. [d] No desired product detected. [e] $NiCl_2{\cdot}6H_2O$ was used. [f] Complex mixture. [g] A grain of iodine was added. [h] 2,6-*Di-tert*-butyl-4-methylphenol (1 equiv.) was added.

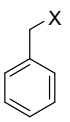
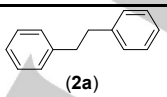
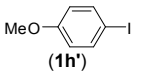
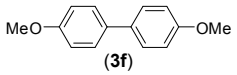
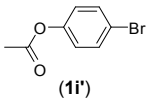
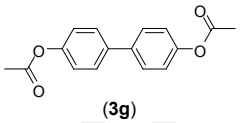
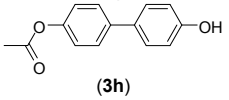
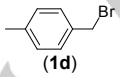
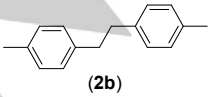
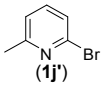
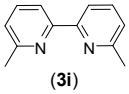
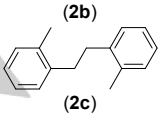
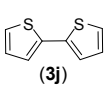
With the optimized conditions in hand, a variety of sterically and electronically diverse substrates were subjected to the reaction to investigate the generality of the protocol, and the results are shown in table 2. The organohalides investigated herein involve the following types: benzyl halides (Table 2, **1a**-**1p**, entries 1-16), aryl halides (**1a'**-**1i'**, entries 17-26), heterocyclic halides (**1j'**-**1l'**, entries 27-29), alkyl halides (**1a''**-**1i''**) including alkenyl halides (**1a''-1c''**, entries 30-38), α-haloacetophenones (**1j''**-**1k''**, entries 39-40), phenyl alkylsulfonates (**1l''-1n''**, entries 41-43). These organohalides were well tolerated, affording the homocoupling products smoothly. The coupling types involved the Csp^3-Csp^3 (entries 1-16, 32-40) and the Csp^2-Csp^2 (entries 17-31, 41-44).

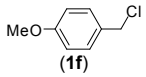
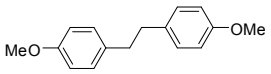
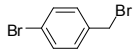
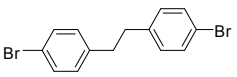
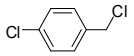
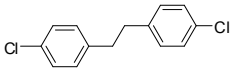
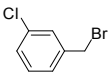
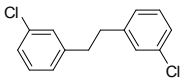
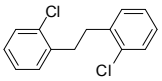
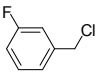
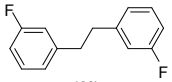
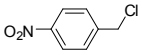
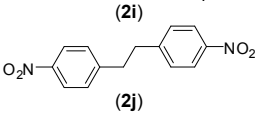
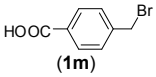
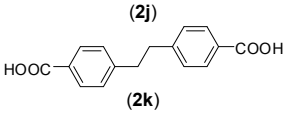
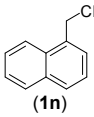
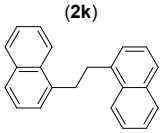
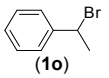
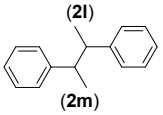
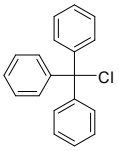
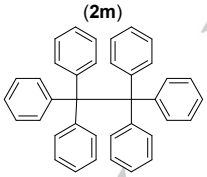
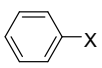
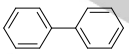
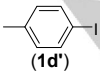
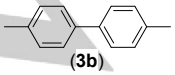
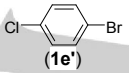
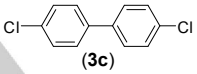
Benzyl halides were the most reactive to undergo the homocoupling reaction, which featured high yields and shorter reaction times (entries 1-16). Both benzyl chlorides (entries 1, 5, 6, 8, 10-12, 14, 16) and benzyl bromides (entries 2, 4, 7, 9, 13, 15) yielded the corresponding bibenzyls with good efficiency. Excellent chemoselectivity was observed when the substrates **1** carrying -NO_2 (entry 12), –COOH (entry 13), and -X (entries 7-11) were subjected to the reaction.

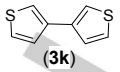
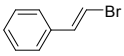
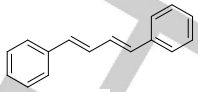
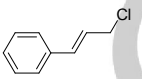
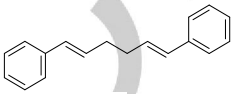
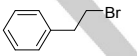
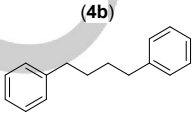
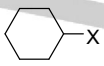
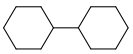
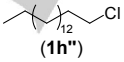
The results also showed that slightly better yields were obtained for the benzyl halides with electron-donating groups (entries 4-6) than those with electron-withdrawing groups (entries 7-13). No obvious influences could be observed when relatively bulky substrates **1n** and **1o** were used (entries 14-15); neither did the benzylhalides with ortho-substituents (**1e** and **1j**, entries 5 and 10). Interestingly, (±)-α-bromoethylbenzene (**1o**) yielded homocoupling product with entire *meso*-selectivity (entry 15). Another unexpected result was also obtained when triphenylmethyl chloride (**1p**) underwent the homocoupling in spite of the lower yield, considering its challenging bulky structure (entry 16).

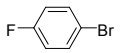
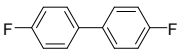
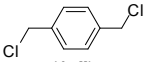
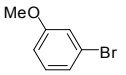
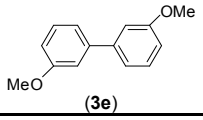
Table 2. The Versatile Homocoupling of Organohalides.



Entry[a]	R-X	R-R	t (h)	Yield (%)[b]	Entry[a]	R-X	R-R	t (h)	Yield (%)[b]
1	**1a** 	 (**2a**)	8	89	24	 (**1h'**)	 (**3f**)	12	91
2	**1b** X=Cl (**1a**) Br(**1b**)	**2a**	8	93	25	 (**1i'**)	 (**3g**)	16	57[d]
3	**1c** I (**1c**)	**2a**	8	95	26	**1i'**	 (**3h**)	48	41
4	 (**1d**)	 (**2b**)	8	96	27	 (**1j'**)	 (**3i**)	24	80
5	 (**1e**)	 (**2c**)	8	92	28	 (**1k'**)	 (**3j**)	24	71

6	 (**1f**)	 (**2d**)	8	96
7	 (**1g**)	 (**2e**)	8	90
8	 (**1h**)	 (**2f**)	8	91
9	 (**1i**)	 (**2g**)	8	89
10	 (**1j**)	 (**2h**)	8	90
11	 (**1k**)	 (**2i**)	8	88
12	 (**1l**)	 (**2j**)	24	71
13	 (**1m**)	 (**2k**)	24	62
14	 (**1n**)	 (**2l**)	12	87
15	 (**1o**)	 (**2m**)	8	91[c]
16	 (**1p**)	 (**2n**)	16	43
17	**1a'** 	 (**3a**)	24	62
18	**1b'** X=Cl (**1a'**) Br(**1b'**) I (**1c'**)	**3a**	16	81
19	**1c'**	**3a**	16	85
20	 (**1d'**)	 (**3b**)	16	88
21	 (**1e'**)	 (**3c**)	16	79

29	 (**1l'**)	 (**3k**)	24	73
30	 (**1a''**)	 (**4a**)	16	89
31	 (**1b''**)	**4a**	16	82
32	 (**1c''**)	 (**4b**)	10	73
33	 (**1d''**)	 (**4c**)	24	82
34	**1e''** 	 (**4d**)	48	61
35	**1f''** X=Cl (**1e''**) Br (**1f''**)	**4d**	24	72
36	**1g''** I (**1g''**)	**4d**	16	78
37	 (**1h''**)	(**4e**)	48	47
38	(**1i''**)	(**4f**)	48	59
39	(**1j''**)	(**4g**)	12	73
40	(**1k''**)	(**4h**)	12	70
41	(**1l''**)	(**3a**)	24	56[d]
42	(**1m''**)	**3a**	24	63[d]
43	(**1n''**)	**3a**	12	84
44	(**1o''**)	(**4i**) Oligomer	1-8 8-16	57[e] --[f]

22	 (**1f'**)	 (**3d**)	16	82	45	 (**1p''**)	Oligomer	0-16	--[g]
23	 (**1g'**)	 (**3e**)	16	82	46	**1b + 1b'**	Homocoupling	16	**2a**[h] **3a**[h]

[a] RX (2 mmol), Sm (2 mmol), $NiCl_2$ (5 mol %), HMPA (2 mmol), THF (10 mL), N_2 atmosphere, reflux. [b] Isolated yields. [c] With 100 % meso-selectivity. [d] About 30 % of substrate remained unreacted. [e] Oligomer was also observed in 8 h. [f] The dimer vanished gradually in next 8 h. [g] Complex mixture. [h] No cross-coupling product was observed, **2a** and **3a** were afforded in their respective yields.

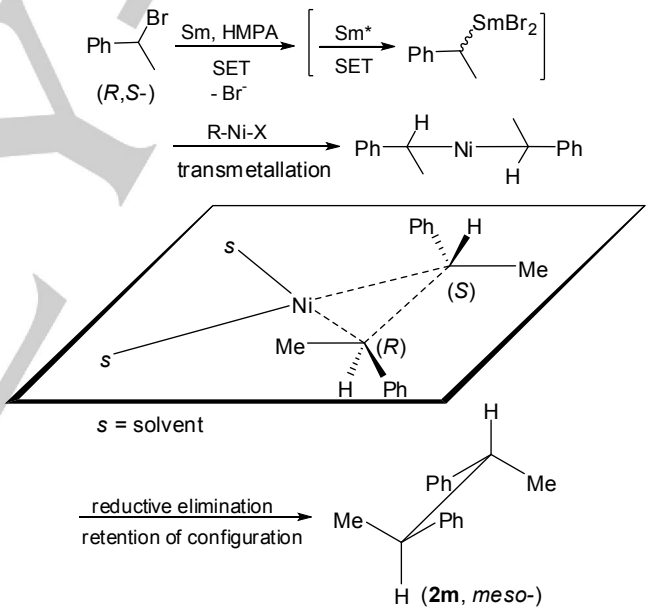
Although longer reaction time was required, aryl halides afforded biaryls with almost similar efficiency compared with benzyl halides (entries 18-26), while chlorobenzene (**1a'**) showed lower reactivity (entry 17). The formation of 4,4'-dichlorobiphenyl (entry 21) and 4,4'-difluorobiphenyl (entry 22) indicates the distinct chemoselectivity between active halides (bromo, iodo) and inert halides (chloro, fluoro). The chemo-selectivity was also observed when heterocyclic halides (**1j'**-**1l'**) were compatible with the reaction conditions (entries 27-29), especially 2-bromo-5-methylpyridine (**1j'**, entry 27), which was considered unstable in samarium reagents in some cases.[8] However, the bromophenylacetate (**1i'**) produced **3g** in 16 h (entry 25), which was then transformed to the monodeacetylation products (**3h**, entry 26) in 48 h.

Among the aliphatic halides (entries 30-38), both configurations of *β*-bromostyrenes (**1a''** and **1b''**, *E*- and *Z*-) underwent the homocoupling smoothly to afford the single product of *E,E*-1,4-diphenylbutadiene (entry 30-31). The coupling of unactivated alkyl chlorides (entries 34-38) without in situ activation with NaI may inspire some interesting development in the field of Ni-catalyzed reductive coupling chemistry other than the known Barbier reactions. However, the reaction efficiency decreased when the molecular chains of the aliphatic halides became longer (entries 34, 37-38).

Further attempts to expand the homocoupling to α-bromoacetophenones (**1j''**-**1k''**) were also successful (entries 39-40). The results showed excellent chemoselectivity between bromo- and ketone groups which cannot tolerate samarium reagents in most cases.[6-9] An remarkable substrate extension showed that phenyl organosulfonates (**1l''**-**1n''**) were also subjected to the reductive homocouplings. As pseudoorganohalides, phenyl trifluoromethanesulfonate (**1n''**) exhibited good reactivity (entry 43), while both phenylsulfonates (**1l''** and **1m'')** afforded biphenyl sluggishly (entries 41-42).

Subsequent investigation showed that *p*-dibromobenzene (**1o''**) yielded the homocoupling product **4i** in 8 h together with oligomer afforded, while the dimer vanished gradually in next 8 h to afford a great quantity of oligomer (entry 44). However, only complex mixture was obtained when bibenzylchloride (**1p''**) was used as the substrate (entry 45). Besides, the cross-coupling between benzyl bromide and bromobenzene was not successful, where only homocoupling products **2a** and **3a** were obtained in their respective yields (entry 46).

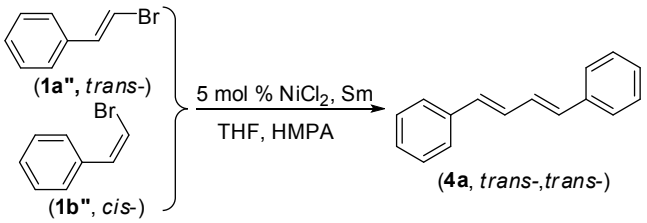
The reaction stereoselectivity may play an important role in the clarification of the mechanism (entries 15, 30-31). It probably implies that *via* the process of single-electron transfer (SET), a radical intermediate followed by a carbanion might be firstly formed during the coupling of Csp^3-Csp^3 (entries 15),[8a] and the successively resulting organosamarium species[11] underwent the transmetallation (Scheme 2). As it is known, a radical or a carbanion actually loses its original configuration,[12,13] which may be initiated by samarium,[12a-d,13a-d] magnesium,[12e,13e] lithium,[13e-k] and Bu_3SnH.[12f,13a,g] The stereochemical reaction involved with such intermediates are mainly influenced by the steric effect and the electronic effect. However, in some particular cases, high steroselectivity was thus achieved by appropriate control of these influencing effects.[12c-d,13d-k]



Scheme 2. The Stereoselectivity of the Homocoupling.

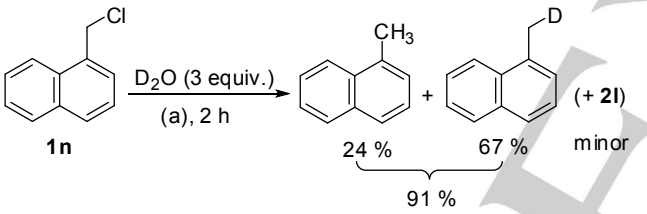
In views of this, the fact that both *R*- and *S*- substrates (**1o)** affording the *meso*-product **2m** (entry 15) may be explained as the stereo adjustment of organosamarium during the transmetallation (Scheme 2), which accommodates the stereo requirement of the Csp^3-Csp^3 coupling. The steric effect plays an important role here in the control of the stereochemistry through the formation of a stable staggered conformation. With the retention of configuration,[14] the subsequent *cis*-reductive elimination thus produce an *meso*-configured product. The results that both *cis*-and *trans*- substrates (**1a''** and **1b''**, entries 30-31) affording a single *trans*-,*trans*- product **4a** (Scheme 3)

may also be explained in this manner. Nevertheless, it is also considered that a different process might be involved in such a coupling of Csp^2-Csp^2 type.[15]



Scheme 3. The Trans-homocoupling of Alkenyl Halides.

However, there still remains a certain doubt for the reaction mechanism. Besides the organosamarium pathway, a potential intermediacy of Ni(I) species[1a,16] may also be taken into account, which is not considered or ruled out in the present proposal. Further experimental evidence was obtained by the performance of the process in the presence of D_2O (Scheme 4). The results provide crucial information about the intermediacy of organosamarium species, due to D incorporation was observed. As a result, a Ni(I)/Ni(III) cycle may not be considered as an alternative process for the catalytic cycle in this case.

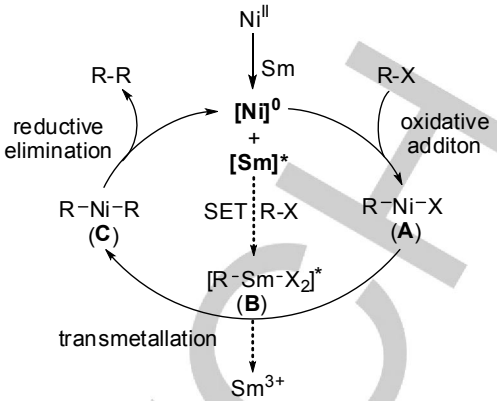


(a) $NiCl_2$ (5 mol %), Sm, THF, HMPA, reflux (as given in Table 2)

Scheme 4. Deuteration of the Intermediate during the Homocoupling.

Nevertheless, an organosamarium species is usually considered unstable and only formed during an *in-situ* transformation.[11] Therefore, it is difficult to realize the stepwise cross-coupling at current stage (Table 2, entry 46).

Based on these results, a plausible mechanism of the homocoupling was proposed as shown in Scheme 5. Nickel(II) may play two roles in this reaction. Firstly, Ni(II) is reduced by samarium, which is believed to activate samarium metal to initiate its reducing ability. Secondly, the resulting Ni(0) undergoes oxidative addition of R-X to furnish complex **A**. Meanwhile, the resulting activated samarium instantly promotes R-X to generate an organosamarium species **B** *via* the single-electron transfer process. Accompanied with the reduction by samarium, the transmetallation of **A** with **B** then occurs to afford R_2Ni (**C**), followed by the reductive elimination to yield the coupling product. Simultaneously Ni(0) species is regenerated, furnishing the catalytic cycle.



Scheme 5. Tentative Mechanism.

Conclusions

In summary, a novel coupling agent of Sm/Ni(II) is demonstrated which shows the extraordinary homocoupling reactivity for widespread organohalides and pseudo-organohalides in the presence of HMPA. With excellent chemoselectivity and stereoselectivity, the reductive homocoupling reaction provides an efficient method for the synthesis of biphenyls, bibenzyls, 1,4-diketones and long-chain hydrocarbons from readily available materials.

Experimental Section

Typical procedure for the preparation of bibenzyl from benzyl bromide

To a mixture of Sm powder (0.3 g, 2 mmol), $NiCl_2$ (0.013 g, 0.1 mmol) in anhydrous THF (10 mL) under a nitrogen atmosphere, HMPA (0.35 ml, 2mmol) and benzyl bromide (0.24 mL, 2 mmol) were added at reflux with magnetic stirring. After completion of the reaction (about 4 h, monitored by TLC), dilute hydrochloric acid (2 M, 5 mL) was added and the resulting mixture was extracted with ethyl acetate (3 × 10 mL). The combined organic layer was washed with brine, dried over anhydrous sodium sulfate, and concentrated under reduced pressure. The crude product was purified with flash chromatography (silica/petroleum ether - ethyl acetate 100 : 1 v/v) to afford 169.5 mg of bibenzyl with 93% yield.

Acknowledgements

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Keywords: homocoupling • organohalide • nickel(II) chloride • samarium • organosulfonate

[1] For recent reviews: a) B. M. Rosen, K. W. Quasdorf, D. A. Wilson, N. Zhang, A.-M. Resmerita, N. K. Garg, V. Percec, *Chem. Rev.* **2011**, *111*,

1346-1416; b) F.-S. Han, *Chem. Soc. Rev.* **2013**, *42*, 5270-5298; c) V. P. Mehta, E. V. Van der Eycken, *Chem. Soc. Rev.* **2011**, *40*, 4925-4936; d) R. Jana, T. P. Pathak, M. S. Sigman, *Chem. Rev.* **2011**, *111*, 1417-1492; e) T. Sperger, I. A. Sanhueza, I. Kalvet, F. Schoenebeck, *Chem. Rev.* **2015**, *115*, 9532-9586; f) D. Ravelli, S. Protti, M. Fagnoni, *Chem. Rev.* **2016**, *116*, 9850–9913; g) S. Roscales, A. G. Csákÿ, *Chem. Soc. Rev.* **2014**, *43*, 8215-8225.

[2] a) S. K. Gurung, S. Thapa, B. Shrestha, R. Giri, *Org. Chem. Front.* **2015**, *2*, 649-653; b) C. E. I. Knappke, S. Grupe, D. Gartner, M. Corpet, C. Gosmini, A. J. von Wangelin, *Chem. Eur. J.* **2014**, *20*, 6828-6842; c) A. Moncomble, P. L. Floch, C. Gosmini, *Chem. Eur. J.* **2009**, *15*, 4770-4774; d) C. C. C. J. Seechurn, M. O. Kitching, T. J. Colacot, V. Snieckus, *Angew. Chem. Int. Ed.* **2012**, *51*, 5062-5085; e) S. Nadri, E. Azadi, A. Ataei, M. Joshaghani, E. Rafiee, *J. Organomet. Chem.* **2011**, *696*, 2966-2970.

[3] a) J. Gu, X. Wang, W. Xue, H. Gong, *Org. Chem. Front.* **2015**, *2*, 1411-1421; b) D. B. Biradar, H.-M. Gau, *Chem. Commun.* **2011**, *47*, 10467-10469; c) M. S. Oderinde, A. Varela-Alvarez, B. Aquila, D. W. Robbins, J. W. Johannes, *J. Org. Chem.* **2015**, *80*, 7642-7651; d) S. Biswas, D. J. Weix, *J. Am. Chem. Soc.* **2013**, *135*, 16192-16197; e) X. Hu, *Chem. Sci.* **2011**, *2*, 1867-1886; f) B. L. H. Taylor, E. R. Jarvo, *J. Org. Chem.* **2011**, *76*, 7573-7576; g) A. H. Cherney, N. T. Kadunce, S. E. Reisman, *J. Am. Chem. Soc.* **2013**, *135*, 7442-7445; h) J. Zhang, G. Lu, J. Xu, H.Sun, Q. Shen, *Org. Lett.* **2016**, *18*, 2860−2863.

[4] a) S. M. Goldup, D. A. Leigh, R. T. McBurney, P. R. McGonigal, A. Plant, *Chem. Sci.* **2010**, *1*, 383-386; b) J. Hashim, C. O. Kappe, *Adv. Synth. Catal.* **2007**, *349*, 2353-2360; c) T. Chen, L. Yang, L. Li, K.-W. Huang, *Tetrahedron* **2012**, *68*, 6152-6157; (d) L.-Y. Liao, X.-R. Kong, X.-F. Duan, *J. Org. Chem.* **2014**, *79*, 777-782; e) M. R. Prinsell, D. A. Everson, D. J. Weix, *Chem. Commun.* **2010**, *46*, 5743-5745; f) S. B. Jhaveri, K. R. Carter, *Chem. Eur. J.* **2008**, *14*, 6845-6848; (g) H. Xu, C. Zhao, Q. Qian, W. Deng, H. Gong, *Chem. Sci.* **2013**, *4*, 4022 - 4029; (h) W. Xue, H. Xu, Z. Liang, Q. Qian, H. Gong, *Org. Lett.* **2014**, *16*, 4984-4987; (i) X. Yu, T. Yang, S. Wang, H. Xu, H. Gong, *Org. Lett.* **2011**, *13*, 2138-2141; (j) S. Khan, A. Ghatak, S. Bhar, *Tetrahedron Lett.* **2015**, *56*, 2480 -2487; (k) Y. Peng, L. Luo, C.-S. Yan, J.-J. Zhang, Y.-W. Wang, *J. Org. Chem.* **2013**, *78*, 10960–10967; (l) Y. Masuda, N. Ishida, M. Murakami, *Eur. J. Org. Chem.* **2016**, 5822-5825.

[5] a) K. Sato, Y. Inoue, T. Mori, A. Sakaue, A. Tarui, M. Omote, I. Kumadaki, A. Ando, *Org. Lett.* **2014**, *16*, 3756-3759; b) D. Toumcanmini, F. Ouazzani, M. Taillefer, *Org. Lett.* **2013**, *15*, 4690-4693; c) Y. Cai, X. Qian, C. Gosmini, *Adv. Synth. Catal.* **2016**, *358*, 2427-2430.

[6] a) J. L. Namy, P. Girard, H. B. Kagan, *Nouv. J. Chim.* **1977**, *1*, 5-7; b) P. Girard, J. L. Namy, H. B. Kagan, *J. Am. Chem. Soc.* **1980**, *102*, 2693-2698.

[7] For books on SmI_2, see: a) S. C. Coote, R. A. Flowers II, T. Skrydstrup, D. J. Procter in *Organic Synthesis Using Samarium Diiodide: Synthetic Strategies, Applications*, RSC Publishing, Cambridge, **2012**; b) D. J. Procter, R. A. Flowers II, T. Skrydstrup in *Organic Synthesis using Samarium Diiodide: A Practical Guide, RSC Publishing, Cambridge*, **2009**; c) X. Just-Baringo, I. Yalavac, D. Procter in *Overcoming synthetic challenges in target synthesis using SmI_2: recent advances, Vol. 40*, RSC Publishing, Cambridge, *Organomet. Chem.*, **2016**, 1-32.

[8] For recent reviews on SmI_2, see: a) M. Szostak, N. J. Fazakerley, D. Parmar, D. J. Procter, *Chem. Rev.* **2014**, *114*, 5959-6039; b) M. Szostak, M. Spain, D. J. Procter, *Chem. Soc. Rev.* **2013**, *42*, 9155-9183; c) C. Beemelmanns, H.-U. Reissig, *Chem. Soc. Rev.* **2011**, *40*, 2199-2210; d) K. Gopalaiah, H. B. Kagan, *Chem. Rec.* **2013**, *13*, 187-208; e) J. M. Concellón, H. Rodríguez-Solla, C. Concellón, V. del Amo, *Chem. Soc. Rev.* **2010**, *39*, 4103-4113; f) T. Nakata, *Chem. Soc. Rev.* **2010**, *39*, 1955-1972.

[9] a) B. K. Banik, *Eur. J. Org. Chem.* **2002**, 2431-2444; b) G. A. Molander, *Chem. Rev.* **1992**, *92*, 29-68; c) S. Talukdar, J.-M. Fang, *J. Org. Chem*, **2001**, *66*, 330-333; d) C. Yu, B. Liu, L. Hu, *J. Org. Chem.* **2001**, *66*, 919-924.

[10] a) K. A. Choquette, D. V. Sadasivam, R. A. Flowers II, *J. Am. Chem. Soc.* **2011**, *133*, 10655-10661; b) A. C. Kimberly, V. S. Dhandapani, A. F. Robert II, *J. Am. Chem. Soc.* **2010**, *132*, 17396-17398; c) D. V. Sadasivam, P. K. S. Antharjanam, E. Prasad, R. A. Flowers II, *J. Am. Chem. Soc.* **2008**, *130*, 7228-7229; d) J. B. Shotwell, J. M. Sealy, R. A. Flowers II, *J. Org. Chem.* **1999**, *64*, 5251-5255; e) H. Farran, S. Hoz, *Org. Lett.* **2008**, *10*, 865-867; f) S. Halder, S. Hoz, *J. Org. Chem.* **2014**, *79*, 2682-2687.

[11] a) D. Curran, M. J. Totleben, *J. Am. Chem. Soc.* **1992**, *114*, 6050-6058; b) F. Hélion, J.-L. Namy, *J. Org. Chem.* **1999**, *64*, 2944-2946; c) P. Wipf S. Venkatraman, *J. Org. Chem.* **1993**, *58*, 3455-3459; d) M. C. Joséand R.-S. Humberto, *Chem. Soc. Rev.* **2004**, *33*, 599-609; e) K. C. Nicolaou P. E. Shelby, S. C. Jason, *Angew. Chem. Int. Ed.* **2009**, *48*, 7140-7165.

[12] a) G. A. Molander, L. S. Harring. *J. Org. Chem.* **1990**, *55*, 6171-6176; b) J. E. Baldwin, S. C. M. Turner, M. G. Moloney, *Tetrahedron* **1994**, *50* 9425-9438; c) M. Inui, A. Nakazaki, S. Kobayashi, *Org. Lett.* **2007**, *9*, 469-472; d) K. Takahashi, T. Honda, *Org. Lett.* **2010**, *12*, 3026-3029; e) B. Méchin, N. Naulet, *J. Organomet. Chem.* **1972**, *9*, 229-236; f) C.-K. Sha, Z.-P. Zhan, F.-S. Wang, *Org. Lett.* **2000**, *2*, 2011-2013.

[13] a) C. F. Sturino, A. G. Fallis, *J. Org. Chem.* **1994**, *59*, 6514-6516; b) T. Mittag, K. L. Christensen, K. B. Lindsay, N. C. Nielsen, T. Skrydstrup, *J. Org. Chem.* **2008**, *73*, 1088-1092; c) J. Saadi, D. Lentz, H.-U. Reissig, *Org. Lett.* **2009**, *11*, 3334-3337; d) J. M. Concellón, P. L. Bernad, E. Bardales, *Org. Lett.* **2001**, *3*, 937-939; e) H. M. Walborsky, A. E. Young *J. Am. Chem. Soc.* **1964**, *86*, 3288-3296; f) I. Coldham, S. Raimbault, P T. Chovatia, J. J. Patel, D. Leonori, N. S. Sheikha, D. T. E. Whittakerb, *Chem. Commun.* **2008**, 4174–4176; g) E. A. Mitchell, A. Peschiulli, N. Lefevre, L. Meerpoel,, B. U. W. Maes, *Chem. Eur. J.* **2012**, *18*, 10092-10142; h) I. Coldham, D. Leonori, T. K. Bengb, R. E. Gawley, *Chem. Commun.* **2009**, 5239–5241; i) T. K. Beng, R. E. Gawley, *J. Am. Chem. Soc.* **2010**, *132*, 12216-12217; j) I. Coldham, J. J. Patel, S. Raimbaulta, D. T. E. Whittaker, *Chem. Commun.* **2007**, 4534-4536; k) I. Coldham, S Raimbault, D. T. E. Whittaker, P. T. Chovatia, D. Leonori, J. J. Patel, N. S. Sheikh, *Chem. Eur. J.* **2010**, *16*, 4082-4090.

[14] a) T. Hu, J. S. Panek, *J. org. chem.* **1999**, *64*, 3000-3001; b) J. S. Panek, C. E. Masse, *J. Org. Chem.* **1997**, *62*, 8290-8291; c) A. K. Mapp C. H. Heathcock, *J. Org. Chem.* **1999**, *64*, 23-27; d) K. Yuki, M. Shindo, K. Shishido, *Tetrahedron Lett.* **2001**, *42*, 2517-2519.

[15] A possible zwitterionic C(carbene)–Ni complex might be involved: (a) J. Liu, Q. Ren, X. Zhang, H. Gong, *Angew. Chem. Int. Ed.* **2016**, *55*, 15544-15548; (b) C. Clarke, C. A. Incerti-Pradillos, H. W. Lam, *J. Am. Chem. Soc.* **2016**, *138*, 8068-8071; (c) J. M. Huggins, R. G. Bergman, *J Am. Chem. Soc*. **1981**, *103*, 3002-3011.

[16] a) X. Wang, Y. Dai, H. Gong, *Top. Curr. Chem. (Z)*, **2016**, *374:43*, doi:10.1007/s41061-016-0042-2; b) T. Moragas, A. Correa, R. Martin, *Chem. Eur. J.* **2014**, *20*, 8242-8258; c) J. Cornella, E. Gómez-Bengoa, R. Martin, *J. Am. Chem. Soc.* **2013**, *135*, 1997-2009; d) A. Velian, S. Lin, A. J. M. Miller, M. W. Day, T. Agapie, *J. Am. Chem. Soc.* **2010**, *132* 6296–6297; e) G. D. Jones, J. L. Martin, C. McFarland, O. R. Allen, R. E. Hall, A. D. Haley, R. J. Brandon, T. Konovalova, P. J. Desrochers, P. Pulay, D. A. J. Vicic, *J. Am. Chem. Soc.* **2006**, *128*, 13175-13183.

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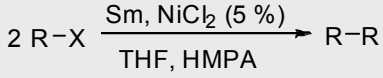
Catalyzed by $NiCl_2$, the homocoupling of organohalides or organosulfonates was accomplished with high efficiency *via* the promotion of samarium metal and HMPA. Excellent chemoselectivity was exhibited between halides and –COOH, $-NO_2$, -X (inerter halogen), heterocyclic ring, ester, and ketone groups. The particular stereoselectivity implied that the reaction mechanism might involve an organosamarium species.



Csp^2-Csp^2 **19 examples** **up to 91 %**

Csp^3-Csp^3 **25 examples** **up to 96 %**

Yongjun Liu, Shuhuan Xiao, Yan Qi, and Feng Du*

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Reductive Homocoupling of Organohalides *via* the Direct Use of Nickel(II) Chloride / Samarium Metal

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