OL | Organic Letters

Letter

Cite This: Org. Lett. XXXX, XXX, XXX–XXX

pubs.acs.org/OrgLett

Use of the 2-Pyridinesulfonyloxy Leaving Group for the Fast Copper-Catalyzed Coupling Reaction at Secondary Alkyl Carbons with Grignard Reagents

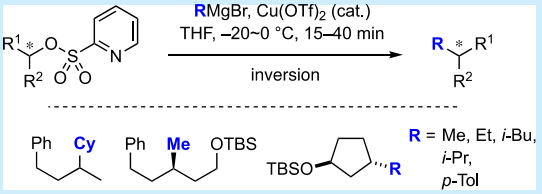
Riku Shinohara,[†] Masao Morita,[†] Narihito Ogawa,[‡] and Yuichi Kobayashi*[,†]

[†]Department of Bioengineering, Tokyo Institute of Technology, Box B-52, Nagatsuta-cho 4259, Midori-ku, Yokohama 226-8501, Japan

[‡]Department of Applied Chemistry, Meiji University, 1-1-1, Higashimita, Tama-ku, Kawasaki 214-8571, Japan

Supporting Information

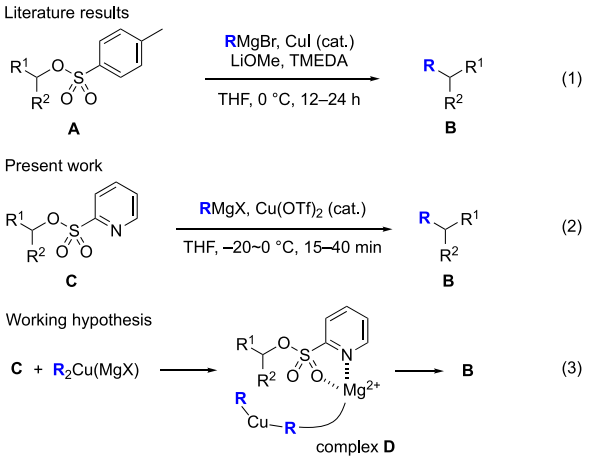
ABSTRACT: Investigation of the copper-catalyzed coupling reaction of 2-pyridinesulfonates with Grignard reagents revealed that reactions with catalytic $Cu(OTf)_2$ were completed in <40 min. The results differed from those of the previous CuI-catalyzed reactions of tosylates in the presence of additives (LiOMe and TMEDA) for 12−24 h. It was shown that the preferred coordination of the leaving group to the reagents accelerated the reaction. Successful reagents were MeMgCl and other RMgX. Complete inversion was established.



The metal-catalyzed coupling reaction of secondary alcohol derivatives with organometallics is a promising method for the construction of a secondary alkyl framework,[1] Allylic, propargylic, and benzylic electrophiles have been well studied, and the stereochemistry has been established.[2] The reactions are promoted by the existing π-carbon moieties. In contrast, coupling at a secondary carbon of inactivated alkyl electrophiles has been published occasionally. Thus, the Ni- and Fe-catalyzed versions[3,4] seem to be a radical process.[5] However, the Ni-catalyzed coupling of racemic substrates possessing a certain functional group proceeds enantioselectively in the presence of a chiral ligand.[6] Ag- and Cu-catalyzed coupling reactions of secondary alkyl halides have also been reported,[7,8] but their stereochemical aspect has not been investigated. Meanwhile, the Cu-catalyzed coupling reaction of tosylates reported by Burns[9] was reinvestigated by Liu, who found RMgBr/CuI/LiOMe/TMEDA for good yields of **B** from tosylates **A** and established an inversion of the stereochemistry[10] (Scheme 1, eq 1). In this reagent system, LiOMe is indispensable, whereas TMEDA was added to suppress the formation of olefins,[11] although the degree of olefin formation was not reported. Later, the coupling was applied by Negishi,[12] who found that 2,2′-bipyridyl was a better ligand than TMEDA. This protocol required a long period of time (24 h), and MeMgX was not examined despite the existence of attractive methyl-substituted bioactive compounds.[12,13] In this regard, we found that the reactivity of MeMgX was lower than that of other RMgBr compounds (vide infra). To break through these limitations, we focused our attention on the design of a leaving group.

On the basis of the transition-state model for the coupling of MeMgBr and $Me_2CuLi{\cdot}LiCl$,[14] the reagent or its appendage was considered to bind to the oxygen atom of the sulfonyl group in tosylate **A**. Furthermore, we speculated that the formation of the complex and/or the subsequent intramolecular reaction to produce **B** was reluctant and thus took 24 h. With this hitherto undiscussed kinetics in mind, we selected 2-pyridinesulfonate **C**[15] as an electrophile (Scheme 1, eq 2). This group was once used for the bromination with $MgBr_2$.[16] As stated, we expected the following effects: (1) the native polarity of the pyridine ring would increase the leaving potency; (2) two coordination sites by nitrogen and oxygen atoms would strongly prefer the formation of complex **D** (eq 3); and/or (3) the coordination would result in electron-withdrawal and, hence, further increase the leaving potency of

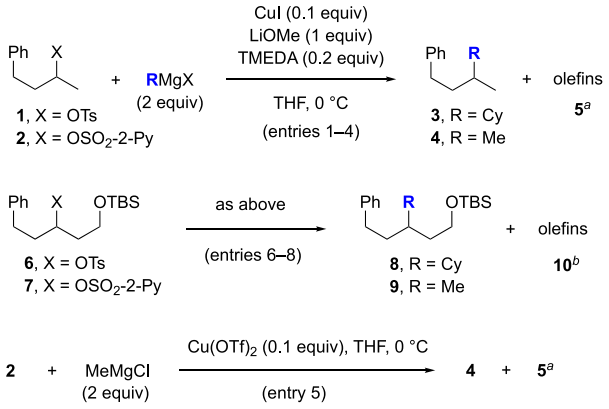
Scheme 1. Background and Proposal of a Highly Reactive Leaving Group



Received: March 19, 2019

DOI: 10.1021/acs.orglett.9b00976
Org. Lett. XXXX, XXX, XXX−XXX

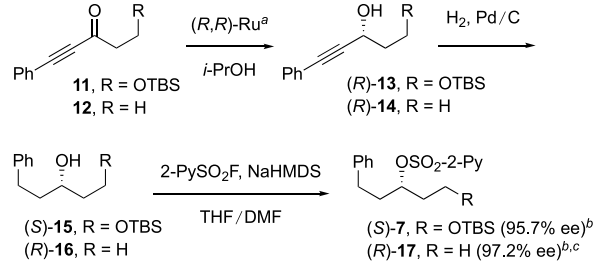
Table 1. Preliminary Study of the Coupling



entry	substrate	RMgX	time	product, yield (%)	recovered, yield (%)
1	**1**	CyMgBr	12 h	**3**, 76[c]	**1**, 0
2	**1**	MeMgCl	24 h	**4**, 11	**1**, 52
3	**2**	CyMgBr	15 min	**3**, 76[c]	**2**, 0
4	**2**	MeMgCl	15 min	**4**, 59[d]	**2**, 0
5[e]	**2**	MeMgCl	30 min	**4**, 77[d]	**2**, 0
6	**6**	CyMgBr	24 h	**8**, 0	**6**, 100
7	**6**	MeMgCl	24 h	**9**, 0	**6**, 100
8	**7**	MeMgCl	20 min	**9**, 73[f]	**7**, 0

[a]Olefins **5**: a mixture of $PhCH_2CH{=}CHMe$ (**5a**), and $Ph(CH_2)_2CH{=}CH_2$ (**5b**). [b]Olefins **10**: a mixture of $PhCH_2CH{=}CH(CH_2)_2OTBS$ (**10a**) and $Ph(CH_2)_2CH{=}CHCH_2OTBS$ (**10b**). [c]**3**/**5a**/**5b** = 85:10:5 (entry 1) and 88:7:5 (entry 3). [d]**4**/**5a**/**5b** = 77:14:9 (entry 4) and 88:9:3 (entry 5). [e]Carried out with $Cu(OTf)_2$ (0.1 equiv) without additives (LiOMe, TMEDA). [f]**9**/**10a**/**10b** = 76:13:11.

Scheme 2. Synthesis of Enantioenriched 2-Pyridinesulfonates



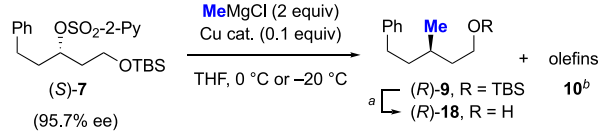
[a]RuCl[(*R*,*R*)-TsDPEN](*p*-cymene). [b]Determined by chiral HPLC. [c]Purity for (*R*)-**16**.

$2\text{-}PySO_3$. Herein, we report the coupling reaction of 2-pyridinesulfonates **C**.

First, the coupling reaction of tosylate **1** with CyMgBr (2 equiv) was carried out at 0 °C in the presence of CuI (0.1 equiv), LiOMe (1 equiv), and TMEDA (0.2 equiv) according to the procedure described in the literature.[10] Tosylate **1** was indeed consumed in 12 h (shorter than the reported time of 24 h) to produce **3**, but olefins **5** were produced as byproducts (Table 1, entry 1, footnote c). In contrast, reaction of **1** with MeMgCl (2 equiv) for 24 h produced **4** only in an 11% yield, with recovery of tosylate **1** in 52% yield (entry 2), indicating that the reactivity of MeMgCl was lower than that of CyMgBr.

On the other hand, the coupling of 2-pyridinesulfonate **2** with CyMgBr was remarkably fast (in 15 min) (entry 3). The ratio of **3** and byproducts **5** was similar to that obtained with

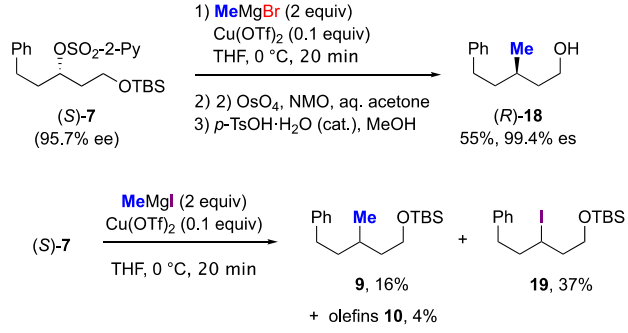
Table 2. Examination of Various Copper Salts



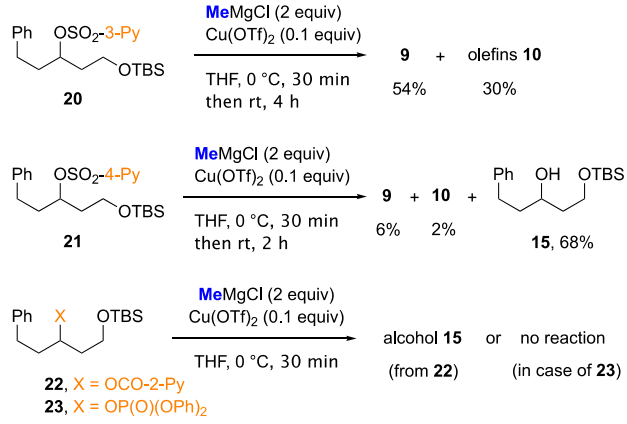
entry	Cu cat.	temp (°C)	time (min)	(*R*)-**9** (%)	es	**10** (%)
1	CuI	0	15	59	88.3	17
2	$Cu(OTf)_2$	0	30	72	98.3	21
3	$Cu(OTf)_2$	–20	30	68	99.2	19
4	$Cu(OMe)_2$	–20	20	63	99.5	16
5	$Cu(OAc)_2$	–20	30	61	98.2	14
6[c]	$Cu(acac)_2$	–20	30	65	99.0	20

[a]Treated as follows for obtaining er by chiral HPLC: (i) OsO_4 (cat.)/NMO, aq. acetone; (ii) *p*-TsOH·H_2O, MeOH. [b]Table 1, footnote b. [c]MeMgCl (4 equiv).

Scheme 3. Coupling of (*S*)-7 with MeMgX (X = Br, I)



Scheme 4. Examination of Other Leaving Groups

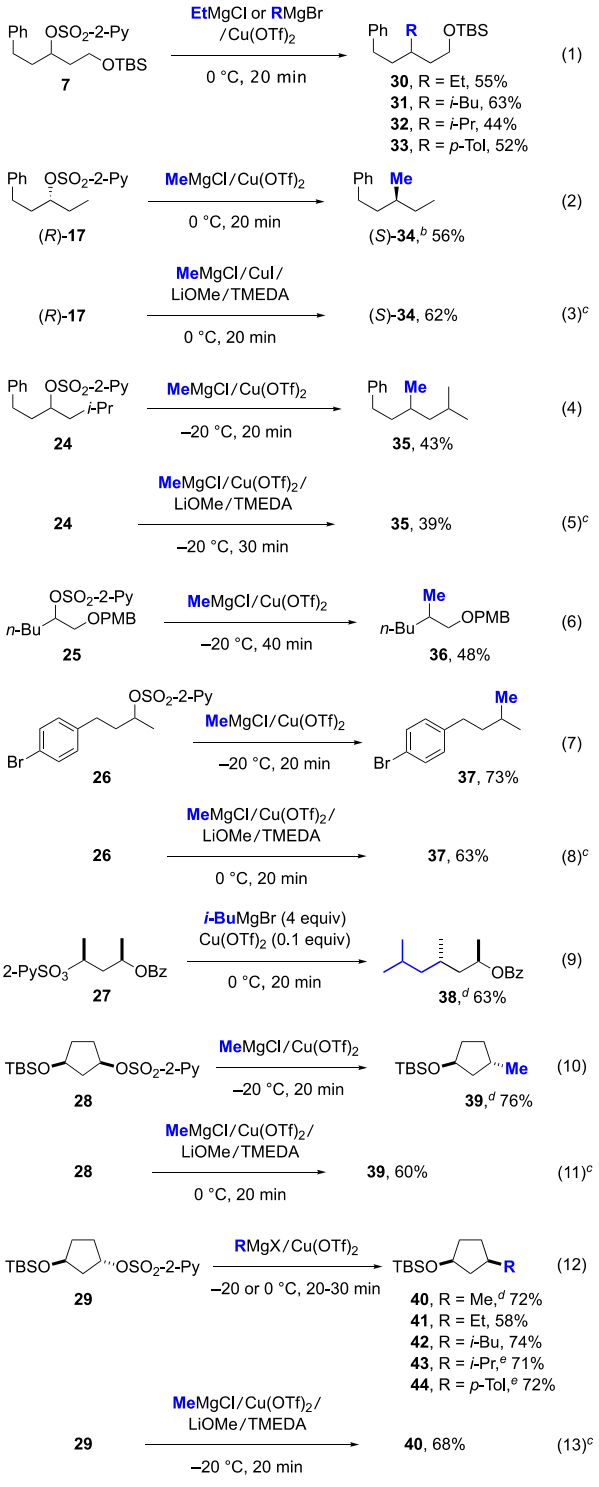


tosylate **1** (footnote c). The coupling reaction with MeMgCl was completed as well and produced **4** and olefins **5** in 59% and 18% yields, respectively (entry 4). The finding that the leaving potency of the 2-pyridinesulfonyloxy group was higher than that of the tosyl group was also confirmed by a competitive experiment using a 1:1 mixture of **1** and **2** (see the SI). The reaction did not proceed without the catalyst (see the SI).

Next, the coupling reaction of tosylate **6** with CyMgBr and MeMgCl disclosed that the reactivity was sensitively affected by the substituent that is bigger than methyl (entries 6 and 7). The results suggest that the substituent interferes markedly in the formation of the complex. A similar tendency could be read from the literature coupling of tosylates possessing an Me or

DOI: 10.1021/acs.orglett.9b00976
Org. Lett. XXXX, XXX, XXX–XXX

Scheme 5. Coupling Reactions of Alkyl 2-Pyridinesulfonates[a]



[a]Reactions were run with RMgX (2 equiv) and $Cu(OTf)_2$ (0.1 equiv) in THF at −20 or 0 °C for 20 min. The olefin byproducts were removed by OsO_4-catalyzed oxidation or by column chromatography. [b]The configuration was determined by $[\alpha]_D$ value. [c]Control experiment with RMgX (2 equiv), Cu salt (0.1 equiv), LiOMe (1 equiv), and TMEDA (0.2 equiv) in THF. [d]The stereochemistry was established by comparison of the NMR data with those reported (see the SI). [e]The *cis* stereochemistry of **43** and **44** were determined by the synthesis and NOESY analysis, respectively (see the SI).

alkyl substituent.[10] In contrast, the reaction of 2-pyridinesulfonate **7** with MeMgCl afforded **9** in 73% yield (entry 8). These results strongly suggest that the formation of complex **D** is the important step. Further investigation led to the discovery that the use of the additives (LiOMe and TMEDA) was not essential for the coupling of 2-pyridinesulfonate **2** (Table 1, entry 5).

The additive-free procedure found in Table 1, entry 5, was applied to coupling of enantioenriched (*S*)-**7** with MeMgX (X = Cl, Br, I) to explore the stereochemical outcome and catalytic activity of other copper salts. This substrate was synthesized with 95.7% ee from ketone **11** via the asymmetric transfer hydrogenation[17] (Scheme 2). Propionaldehyde-derived ketone **12** was also converted to (*R*)-**17**, which was later subjected to the coupling reaction.

The coupling reaction of (*S*)-**7** with MeMgCl was followed by oxidative removal of olefins **10** and TBS desilylation (Table 2, footnote a). The absolute configuration of the resulting alcohol (*R*)-**18** was determined by comparing the $[\alpha]_D$ value with the published data,[18] and the enantiomeric ratio (er) of (*R*)-**18** determined by chiral HPLC was converted to the enantiospecificity (es).[19] CuI gave (*R*)-**9** with a somewhat low enantiospecificity (es) of 88.3% (entry 1). We deemed that the S_N2 reaction with the iodide ion originating from CuI took place ahead of the coupling. Based on the result, copper salts consisting of less nucleophilic counteranions were next examined. The catalytic activity of CuCl and CuCN were marginal and low, respectively (data not shown). The $Cu(OTf)_2$-catalyzed coupling shown in entry 8 of Table 1 was run with (*S*)-**7** to afford (*R*)-**9** in 72% yield with 98.3% es (entry 2). A reaction at −20 °C gave similar yield and ee in 30 min (entry 3), indicating that strictly controlled reaction conditions are not necessary. Similarly high levels of es were recorded with $Cu(OMe)_2$ and $Cu(OAc)_2$, but the yields were slightly low (entries 4 and 5). $Cu(acac)_2$ required 4 equiv of MeMgCl (entries 6). Olefins **10** produced in all cases in a range of 14−22% were roughly a similar level to that observed using the published reagent/catalyst system (Table 1, entry 8). Consequently, the protocol using $Cu(OTf)_2$ at temperatures between −20 to 0 °C for 15−30 min was used for further study.

Next, MeMgX (X = Br, I) were used for the coupling reaction to determine the effect of the bromide and iodide anions (Scheme 3). The coupling reaction with MeMgBr proceeded with 99% es to afford (*R*)-**18** in 55% yield. However, MeMgI gave a mixture of **9** and iodide **19** in 16% and 37% yields, respectively. The competing iodination might account for the partial racemization observed for the CuI-catalyzed coupling (Table 2, entry 1).

Structurally similar leaving groups or those used for allylic substitution were subjected to $Cu(OTf)_2$-catalyzed substitution with MeMgCl (Scheme 4). 3-Pyridinesulfonate **20** was less reactive than **7** and afforded **9** in 54% yield after 4 h at rt. A worse result was the production of alcohol **15** from 4-pyridinesulfonate **21**. These results support the notation that the coordination of the leaving group to Mg^{2+} is a crucial step. The picolinoxy leaving group developed previously for the allylic substitution of secondary allylic substrates[20] did not promote coupling of **22** and instead afforded alcohol **15**. Phosphate **23** was completely unreactive.

In order to evaluate the $Cu(OTf)_2$-catalyzed coupling reaction established above, we applied the reaction to pyridinesulfonates delineated in Scheme 5. Several reactions

DOI: 10.1021/acs.orglett.9b00976
Org. Lett. XXXX, XXX, XXX−XXX

were also examined in the presence of the additives (LiOMe, TMEDA). In addition to the products, the olefins and in some cases the corresponding alcohols were coproduced as described in the Supporting Information. The olefins were eliminated by OsO_4-catalyzed dihydroxylation or chromatography to afford pure coupling products. In all entries, the coupling reactions at −20 or 0 °C were completed in 20−40 min. Coupling reaction of **7** with EtMgCl and *i*-BuMgBr gave **30** and **31** in moderate yields, whereas *i*-Pr was delivered in a somewhat low yield (eq 1). The *p*-Tol group was attached in 52% yield even though generally being less nucleophilic than alkyl reagents. Enantioenriched substrate (*R*)-**17** afforded somewhat volatile (*S*)-**34** (eq 2) and the inversion reaction was proven by the *S* configuration, which was confirmed by comparison of $[\alpha]_D$ with the published data: $[\alpha]_D^{23}$ +18 (*c* 1.0, $CHCl_3$); lit.[21] $[\alpha]_D^{25.5}$ +18.1 (*c* 1.7, $CHCl_3$). A reaction examined in the presence of LiOMe and TMEDA also gave (*S*)-**34** in 62% yield ($[\alpha]_D^{22}$ +17 (*c* 1.70, $CHCl_3$)) (eq 3). Substituents on **24** and **25** affected the reaction to afford **35** and **36** in somewhat low yields (eqs 4 and 6). Once again, the noticeable effect of LiOMe and TMEDA was marginally observed on the reaction of **24** (eq 5). In contrast to these substrates, substrate **26** possessing the methyl substituent underwent a coupling reaction without and with LiOMe/TMEDA to afford **37** in 73% and 63% yields, respectively (eqs 7 and 8). The Br−phenyl bond was not damaged during the reaction. Pyridinesulfonate **27** stereoselectively afforded **38** (eq 9). This product was previously synthesized by the CuI-catalyzed coupling reaction of the corresponding tosylate under modified reaction conditions using 2,2′-bipyridyl but took 24 h at 0 °C.[12]

Pyridinesulfonates **28** and **29** derived from stereoisomeric cyclopentanols also proceeded stereoselectively to afford **39** and **40** in 76% and 72% yields, respectively, on reactions with MeMgCl/$Cu(OTf)_2$ (cat.) (eqs 10 and 12). The NMR data of the derived alcohols were consistent with the published data.[22] Similar results were also obtained by the LiOMe/TMEDA-assisted reaction (eqs 11 and 13). Other Grignard reagents produced coupling products **41**−**44** stereoselectively from **29** in 58−74% yields.

In conclusion, the 2-pyridinesulfonyloxy leaving group designed with the expectations mentioned above was a new booster that allowed the alkyl coupling reaction to be completed in 15−40 min at −20 or 0 °C. The use of $Cu(OTf)_2$ as a catalyst was sufficient for the reaction, and the additives (LiOMe, TMEDA) that were indispensable for the previous couplings of tosylates were no longer necessary. Importantly, the present reaction could be applied to the less reactive MeMgCl.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.9b00976.

Experimental procedures, compound characterization data, chiral HPLC analysis, and NMR spectra (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: ykobayas@bio.titech.ac.jp.

ORCID

Yuichi Kobayashi: 0000-0002-4385-9531

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work was supported by KAKENHI Grant No. 26410111.

■ REFERENCES

(1) (a) Choi, J.; Fu, G. C. Transition Metal−Catalyzed Alkyl-Alkyl Bond Formation: Another Dimension in Cross-Coupling Chemistry. *Science* **2017**, *356*, 152. (b) Kambe, N.; Iwasaki, T.; Terao, J. Pd-Catalyzed Cross-Coupling Reactions of Alkyl Halides. *Chem. Soc. Rev.* **2011**, *40*, 4937−4947. (c) Jana, R.; Pathak, T. P.; Sigman, M. S. Advances in Transition Metal (Pd,Ni,Fe)-Catalyzed Cross-Coupling Reactions Using Alkyl-Organometallics as Reaction Partners. *Chem. Rev.* **2011**, *111*, 1417−1492. (d) Rudolph, A.; Lautens, M. Secondary Alkyl Halides in Transition-Metal-Catalyzed Cross-Coupling Reactions. *Angew. Chem., Int. Ed.* **2009**, *48*, 2656−2670.

(2) (a) Falciola, C. A.; Alexakis, A. Copper-Catalyzed Asymmetric Allylic Alkylation. *Eur. J. Org. Chem.* **2008**, *2008*, 3765−3780. (b) Breit, B.; Schmidt, Y. Directed Reactions of Organocopper Reagents. *Chem. Rev.* **2008**, *108*, 2928−2951. (c) Lu, Z.; Ma, S. Metal-Catalyzed Enantioselective Allylation in Asymmetric Synthesis. *Angew. Chem., Int. Ed.* **2008**, *47*, 258−297. (d) Kar, A.; Argade, N. P. A Concise Account of Recent S_N2' Grignard Coupling Reactions in Organic Synthesis. *Synthesis* **2005**, *2005*, 2995−3022.

(3) (a) Zhou, J. S.; Fu, G. C. Cross-Couplings of Unactivated Secondary Alkyl Halides: Room-Temperature Nickel-Catalyzed Negishi Reactions of Alkyl Bromides and Iodides. *J. Am. Chem. Soc.* **2003**, *125*, 14726−14727. (b) Saito, B.; Fu, G. C. Alkyl−Alkyl Suzuki Cross-Couplings of Unactivated Secondary Alkyl Halides at Room Temperature. *J. Am. Chem. Soc.* **2007**, *129*, 9602−9603. (c) Ren, P.; Vechorkin, O.; von Allmen, K.; Scopelliti, R.; Hu, X. A Structure−Activity Study of Ni-Catalyzed Alkyl−Alkyl Kumada Coupling. Improved Catalysts for Coupling of Secondary Alkyl Halides. *J. Am. Chem. Soc.* **2011**, *133*, 7084−7095. (d) Qin, T.; Cornella, J.; Li, C.; Malins, L. R.; Edwards, J. T.; Kawamura, S.; Maxwell, B. D.; Eastgate, M. D.; Baran, P. S. A General Alkyl-Alkyl Cross-Coupling enabled by Redox-Active Esters and Alkylzinc Reagents. *Science* **2016**, *352*, 801−805. (e) Lu, X.; Xiao, B.; Zhang, Z.; Gong, T.; Su, W.; Yi, J.; Fu, Y.; Liu, L. Practical Carbon−Carbon Bond Formation from Olefins through Nickel-Catalyzed Reductive Olefin Hydrocarbonation. *Nat. Commun.* **2016**, *7*, 11129.

(4) Hatakeyama, T.; Hashimoto, T.; Kathriarachchi, K. K. A. D. S.; Zenmyo, T.; Seike, H.; Nakamura, M. Iron-Catalyzed Alkyl−Alkyl Suzuki−Miyaura Coupling. *Angew. Chem., Int. Ed.* **2012**, *51*, 8834−8837.

(5) Phapale, V. B.; Buñuel, E.; García-Iglesias, M.; Cárdenas, D. J. Ni-Catalyzed Cascade Formation of $C(sp^3)-C(sp^3)$ Bonds by Cyclization and Cross-Coupling Reactions of Iodoalkanes with Alkyl Zinc Halides. *Angew. Chem., Int. Ed.* **2007**, *46*, 8790−8795.

(6) (a) Saito, B.; Fu, G. C. Enantioselective Alkyl−Alkyl Suzuki Cross-Couplings of Unactivated Homobenzylic Halides. *J. Am. Chem. Soc.* **2008**, *130*, 6694−6695. (b) Owston, N. A.; Fu, G. C. Asymmetric Alkyl−Alkyl Cross-Couplings of Unactivated Secondary Alkyl Electrophiles: Stereoconvergent Suzuki Reactions of Racemic Acylated Halohydrins. *J. Am. Chem. Soc.* **2010**, *132*, 11908−11909. (c) Lu, Z.; Wilsily, A.; Fu, G. C. Stereoconvergent Amine-Directed Alkyl−Alkyl Suzuki Reactions of Unactivated Secondary Alkyl Chlorides. *J. Am. Chem. Soc.* **2011**, *133*, 8154−8157. (d) Wilsily, A.; Tramutola, F.; Owston, N. A.; Fu, G. C. New Directing Groups for Metal-Catalyzed Asymmetric Carbon−Carbon Bond-Forming Processes: Stereoconvergent Alkyl−Alkyl Suzuki Cross-Couplings of Unactivated Electrophiles. *J. Am. Chem. Soc.* **2012**, *134*, 5794−5797.

DOI: 10.1021/acs.orglett.9b00976
Org. Lett. XXXX, XXX, XXX−XXX

(7) Someya, H.; Yorimitsu, H.; Oshima, K. Silver-Catalyzed Cross-Coupling Reactions of Alkyl Bromides with Alkyl or Aryl Grignard Reagents. *Tetrahedron Lett.* **2009**, *50*, 3270−3272.
(8) Shen, R.; Iwasaki, T.; Terao, J.; Kambe, N. Copper-Catalyzed Coupling Reaction of Unactivated Secondary Alkyl Iodides with Alkyl Grignard Reagents in the Presence of 1,3-Butadiene as an Effective Additive. *Chem. Commun.* **2012**, *48*, 9313−9315.
(9) Burns, D. H.; Miller, J. D.; Chan, H.-K.; Delaney, M. O. Scope and Utility of a New Soluble Copper Catalyst [CuBr−LiSPh−LiBr−THF]: A Comparison with Other Copper Catalysts in Their Ability to Couple One Equivalent of a Grignard Reagent with an Alkyl Sulfonate. *J. Am. Chem. Soc.* **1997**, *119*, 2125−2133.
(10) Yang, C.-T.; Zhang, Z.-Q.; Liang, J.; Liu, J.-H.; Lu, X.-Y.; Chen, H.-H.; Liu, L. Copper-Catalyzed Cross-Coupling of Nonactivated Secondary Alkyl Halides and Tosylates with Secondary Alkyl Grignard Reagents. *J. Am. Chem. Soc.* **2012**, *134*, 11124−11127.
(11) (a) Nakamura, M.; Matsuo, K.; Ito, S.; Nakamura, E. Iron-Catalyzed Cross-Coupling of Primary and Secondary Alkyl Halides with Aryl Grignard Reagents. *J. Am. Chem. Soc.* **2004**, *126*, 3686−3687. (b) Cahiez, G.; Habiak, V.; Duplais, C.; Moyeux, A. Iron-Catalyzed Alkylations of Aromatic Grignard Reagents. *Angew. Chem., Int. Ed.* **2007**, *46*, 4364−4366. (c) Fürstner, A.; Martin, R.; Krause, H.; Seidel, G.; Goddard, R.; Lehmann, C. W. Preparation, Structure, and Reactivity of Nonstabilized Organoiron Compounds. Implications for Iron-Catalyzed Cross Coupling Reactions. *J. Am. Chem. Soc.* **2008**, *130*, 8773−8787. (d) Noda, D.; Sunada, Y.; Hatakeyama, T.; Nakamura, M.; Nagashima, H. Effect of TMEDA on Iron-Catalyzed Coupling Reactions of ArMgX with Alkyl Halides. *J. Am. Chem. Soc.* **2009**, *131*, 6078−6079. (e) Hatakeyama, T.; Hashimoto, T.; Kondo, Y.; Fujiwara, Y.; Seike, H.; Takaya, H.; Tamada, Y.; Ono, T.; Nakamura, M. Iron-Catalyzed Suzuki−Miyaura Coupling of Alkyl Halides. *J. Am. Chem. Soc.* **2010**, *132*, 10674−10676.
(12) Xu, S.; Oda, A.; Bobinski, T.; Li, H.; Matsueda, Y.; Negishi, E. Highly Efficient, Convergent, and Enantioselective Synthesis of Phthioceranic Acid. *Angew. Chem., Int. Ed.* **2015**, *54*, 9319−9322.
(13) (a) Murayama, T.; Nozaki, K. Single-Step Construction of the *anti*-Deoxypropionate Motif from Propylene: Formal Total Synthesis of the Cuticular Hydrocarbons Isolated from *Antitrogus parvulus*. *Angew. Chem., Int. Ed.* **2018**, *57*, 11394−11398. (b) Ota, Y.; Murayama, T.; Nozaki, K. One-Step Catalytic Asymmetric Synthesis of All-*syn* Deoxypropionate Motif from Propylene: Total synthesis of (2*R*,4*R*,6*R*,8*R*)-2,4,6,8-Tetramethyldecanoic Acid. *Proc. Natl. Acad. Sci. U. S. A.* **2016**, *113*, 2857−2861. (c) Herber, C.; Breit, B. Enantioselective Total Synthesis and Determination of the Absolute Configuration of the 4,6,8,10,16,18-Hexamethyldocosane from *Antitrogus parvulus*. *Angew. Chem., Int. Ed.* **2005**, *44*, 5267−5269.
(14) (a) Mori, S.; Nakamura, E.; Morokuma, K. Mechanism of S_N2 Alkylation Reactions of Lithium Organocuprate Clusters with Alkyl Halides and Epoxides. Solvent Effects, BF_3 Effects, and Trans-Diaxial Epoxide Opening. *J. Am. Chem. Soc.* **2000**, *122*, 7294−7307. (b) Yoshikai, N.; Nakamura, E. Mechanisms of Nucleophilic Organocopper(I) Reactions. *Chem. Rev.* **2012**, *112*, 2339−2372.
(15) 2-Pyridinesulfonates were synthesized from the corresponding alchohols with 2-PySO_2F and NaHMDS in THF and DMF.
(16) Hanessian, S.; Kagotani, M.; Komaglou, K. Design and Reactivity of Organic Functional Groups − 2-Pyridylsulfonates as Nucleofugal Esters: Remarkably Mild Transformations into Halides and Olefins. *Heterocycles* **1989**, *28*, 1115−1120.
(17) Matsumura, K.; Hashiguchi, S.; Ikariya, T.; Noyori, R. Asymmetric Transfer Hydrogenation of α,β-Acetylenic Ketones. *J. Am. Chem. Soc.* **1997**, *119*, 8738.
(18) Gao, Z.; Fletcher, S. P. Asymmetric Conjugate Addition of Alkylzirconium Reagents to α,β-Unsaturated Thioesters: Access to Fragrances and Acyclic Stereochemical Arrays. *Chem. Commun.* **2017**, *53*, 10216−10219.
(19) (a) Denmark, S. E.; Vogler, T. Synthesis and Reactivity of Enantiomerically Enriched Thiiranium Ions. *Chem. - Eur. J.* **2009**, *15*, 11737−11745. (b) Larouche-Gauthier, R.; Elford, T. G.; Aggarwal, V. K. Ate Complexes of Secondary Boronic Esters as Chiral Organometallic-Type Nucleophiles for Asymmetric Synthesis. *J. Am. Chem. Soc.* **2011**, *133*, 16794−16797.
(20) (a) Kiyotsuka, Y.; Acharya, H. P.; Katayama, Y.; Hyodo, T.; Kobayashi, Y. Picolinoxy Group, a New Leaving Group for anti S_N2' Selective Allylic Substitution with Aryl Anions Based on Grignard Reagents. *Org. Lett.* **2008**, *10*, 1719−1722. (b) Kaneko, Y.; Kiyotsuka, Y.; Acharya, H. P.; Kobayashi, Y. Construction of a Quaternary Carbon at the Carbonyl Carbon of the Cyclohexane Ring. *Chem. Commun.* **2010**, *46*, 5482−5484. (c) Feng, C.; Kobayashi, Y. Allylic Substitution for Construction of a Chiral Quaternary Carbon Possessing an Aryl Group. *J. Org. Chem.* **2013**, *78*, 3755−3766.
(21) McCabe, R. W.; Parri, O. L.; Price, A. H. Synthesis and Mesophase Formation of Branched-Chain Bis-l,2-dithiolatonickel(II) Complexes. *J. Mater. Chem.* **1993**, *3*, 609−613.
(22) Kennedy, N.; Cohen, T. The Stereoselective Reductions of Ketones to the Most Thermodynamically Stable Alcohols using Lithium and Hydrated Salts of Common Transition Metals. *J. Org. Chem.* **2015**, *80*, 8134−8141.

DOI: 10.1021/acs.orglett.9b00976
Org. Lett. XXXX, XXX, XXX−XXX