

# 1,10-Phenanthroline or Electron Promoted Cyanation of Aryl Iodides

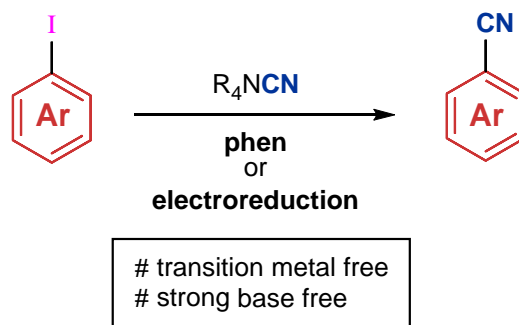
Koichi Mitsudo\*<sup>a</sup>  
 Kazuki Yoshioka<sup>a</sup>  
 Takayuki Hirata<sup>a</sup>  
 Hiroki Mandai<sup>a</sup>  
 Koji Midorikawa<sup>b</sup>  
 Seiji Suga\*<sup>a</sup>

<sup>a</sup> Division of Applied Chemistry, Graduate School of Natural Science and Technology, Okayama University, 3-1-1 Tsushima-naka, Kita-ku, Okayama 700-8530, Japan

<sup>b</sup> Nippon Chemicals Co., Ltd., 8-15, 4-Chome, Nihonbashi-Honchou, Chuo-Ku, Tokyo 103-0023, Japan

mitsudo@cc.okayama-u.ac.jp; suga@cc.okayama-u.ac.jp

[Click here to insert a dedication.](#)



# with phen  
10 examples  
up to 78% yield

# by electroreduction  
8 examples  
up to 70% yield

Received:  
Accepted:  
Published online:  
DOI:

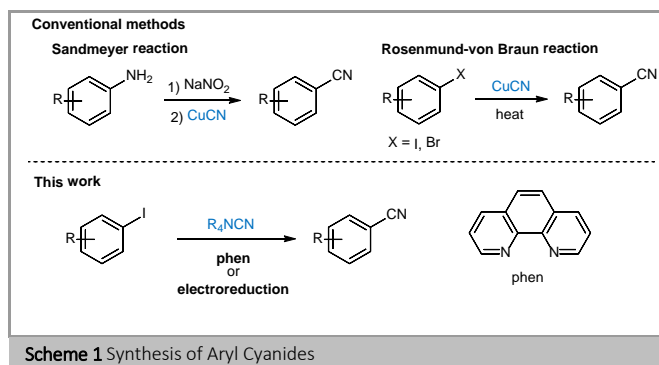
**Abstract** 1,10-Phenanthroline promoted cyanation of aryl iodides has been developed. Phenanthroline worked as an organocatalyst for the reaction of aryl iodides with tetraalkylammonium cyanide to afford aryl cyanides. The similar reactions occurred via electro-reductive processes.

**Key words** Cyanation, Metal free, Organocatalyst, Electroreduction, Phenanthroline,  $S_{RN}1$ , Electron transfer

Aryl cyanides are a significant motif of pharmaceuticals, natural products, and organic materials.<sup>1</sup> They are also important as precursors because the nitrile group can be transformed into a wide variety of functional groups, such as amides, carboxylic acids, imines, ketones, and amines. The most conventional ways to synthesize aryl cyanides are the Sandmeyer reactions<sup>2</sup> and the Rosenmund–von Braun reactions<sup>3</sup> (Scheme 1). Sandmeyer reactions require diazonium salts, which are sometimes explosive, whereas Rosenmund–von Braun reactions usually require harsh reaction conditions. Additionally, a stoichiometric amount of copper cyanide should be used, which is often problematic in a large-scale synthesis. In the past decades, transition metal-catalyzed cyanation using aryl halides or arylboronic acids had been studied intensively.<sup>4,5</sup> For instance, Buchwald et al. reported copper-catalyzed Rosenmund–von Braun-type reaction.<sup>5a,5b</sup> Recently, cyanation reactions using nonmetallic cyanating agents have also been reported. Shen and co-workers reported a palladium-catalyzed cyanation reaction using ethyl cyanoacetate as a cyanating agent.<sup>6a</sup> Wang reported iron-catalyzed cyanation using hypervalent iodonium salts.<sup>6b</sup> Itami and Yamaguchi reported Ni-catalyzed cyanation using aminoacetonitriles as cyanating agents.<sup>6c</sup> Although there have been many other reports on cyanation reactions, most of them require the use of a stoichiometric amount of metal cyanide or of transition metal catalysts. In contrast, there have been only a few reports on cyanation reactions by metal-free approaches.<sup>7</sup> Kita reported hypervalent iodine-mediated direct cyanation of

electron-rich heteroaromatics.<sup>7a,7b</sup> Lewis acid-catalyzed direct cyanation of indoles and pyrroles was reported by Wang group.<sup>7c</sup> Quite recently, Nicewicz reported direct cyanation reactions using photoredox catalysts.<sup>7c</sup> In another approach, Novi reported electro-reductive cyanation using diazosulfides as the source of aryl radicals.<sup>8</sup> Although these reactions proceeded with a catalytic amount of electricity, a large amount (20 equiv) of  $\text{Bu}_4\text{NCN}$  was required for the reaction and the reaction scope was limited.

Meanwhile,  $\text{KOt-Bu}$  or  $\text{NaOt-Bu}$ -mediated cross-coupling reactions between aryl halides and arenes have received considerable attention as novel transition metal-free cross-coupling reactions.<sup>9</sup> These reactions are expected to proceed via the  $S_{RN}1$  mechanism. A key step is single-electron transfer (SET) from  $\text{MOt-Bu}$ /diamine ( $\text{M} = \text{K}$  or  $\text{Na}$ ) to aryl halides to generate aryl radical species that react with arenes. We considered that thus-generated aryl radical species would be applicable for other reactions such as cyanation. Aryl cyanides would be obtained when aryl halides react with a cyanating agent. On the basis of this hypothesis, we started the study of  $\text{MOt-Bu}$ -mediated cyanation reaction of aryl halides. Although the desired reactions proceeded, we unexpectedly found that  $\text{MOt-Bu}$  was unnecessary and a catalytic amount of 1,10-phenanthroline (phen) promoted cyanation reactions. Similar reactions could be realized by electroreduction. We herein report the first phen or electron promoted cyanation reactions of aryl halides in a metal-free fashion.



On the basis of our preliminary hypothesis, we first carried out *MOt*-Bu-mediated cyanation using 1-iodonaphthalene (**1a**) as a model compound (Table 1). In the presence of *NaOt*-Bu (2.0 equiv) and 1,10-phenanthroline (phen, 10 mol%), **1a** was treated with several cyanide sources at 150 °C (Entries 1–5). NaCN and KCN were ineffective (Entries 1 and 2). With Me<sub>3</sub>SiCN, the desired cyanated product **2a** was obtained in 14% yield with 39% yield of the dehalogenated product **3a** (Entry 3). Use of tetraalkylammonium cyanide gave better results (Entries 4 and 5). With tetrabutylammonium cyanide (Bu<sub>4</sub>NCN) or tetraethylammonium cyanide (Et<sub>4</sub>NCN), **2a** was obtained in respective yields of 20% and 29%. Solvent effect was examined next. Among several solvents, dimethyl sulfoxide (DMSO) gave the best results. For instance, yield of **2a** decreased drastically in dimethylformamide (DMF) (6% yield) and in CH<sub>3</sub>CN (19% yield). Using *KOt*-Bu instead of *NaOt*-Bu, we obtained **2a** and **3a** in similar yields (Entry 6). Decreasing the amount of *KOt*-Bu to 1.0 equiv increased the yield of **2a** to 40%. Surprisingly, the cyanation proceeded even without a base, and **2a** was obtained in 32% yield (Entry 7).<sup>10</sup> This result suggests that phen itself can be used as an organocatalyst for the cyanation. Increasing the amount of phen increased the yield of **2a**. With 50 mol% of phen, **2a** was obtained in 45% yield (Entry 8). The reaction was finished within 3 h under the conditions used. Use of 80 mol% of phen gave a similar result to that of 50 mol% of phen (Entry 9). These results are quite different from the results of previously reported *MOt*-Bu-mediated cross-coupling reactions, which did not proceed without *MOt*-Bu. Although the reason is not clear at present time, the reduction potentials of iodoarene and phen were rather close (see cyclic voltammetry in SI), which would lead SET from phen to iodoarene..

**Table 1** Cyanation of **1a** Under Various Conditions

Entry	CN <sup>-</sup> Source	Base	<b>2a</b> (%) <sup>a</sup>	<b>3a</b> (%) <sup>a</sup>	<b>1a</b> (%) <sup>a</sup>
1	NaCN	<i>NaOt</i> -Bu	1	8	N.D. <sup>b</sup>
2	KCN	<i>NaOt</i> -Bu	N.D.	11	N.D.
3	Me <sub>3</sub> SiCN	<i>NaOt</i> -Bu	14	39	12
4	Bu <sub>4</sub> NCN	<i>NaOt</i> -Bu	20	69	N.D.
5	Et <sub>4</sub> NCN	<i>NaOt</i> -Bu	29 (6) <sup>c</sup> (19) <sup>d</sup>	66 (94) <sup>c</sup> (31) <sup>d</sup>	N.D. (43) <sup>c</sup> (N.D.) <sup>d</sup>
6	Et <sub>4</sub> NCN	<i>KOt</i> -Bu	29 (40) <sup>e</sup>	60 (55) <sup>e</sup>	N.D.
7	Et <sub>4</sub> NCN	None	32	49	N.D.

g <sup>f</sup>	Et <sub>4</sub> NCN	None	45 (48) <sup>g</sup>	46 (47) <sup>g</sup>	N.D. (N.D.) <sup>g</sup>
9 <sup>h</sup>	Et <sub>4</sub> NCN	None	47	50	N.D.

<sup>a</sup>Determined by gas chromatography (GC) analysis with dodecane as an internal standard.

<sup>b</sup>Not detected.

<sup>c</sup>Performed in DMF.

<sup>d</sup>Performed in CH<sub>3</sub>CN.

<sup>e</sup>Performed with 1.0 equiv of base.

<sup>f</sup>Performed with 50 mol% of phen.

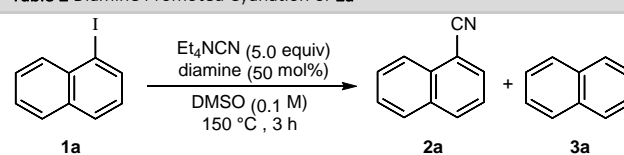
<sup>g</sup>Performed for 3h.

<sup>h</sup>Performed with 80 mol% of phen.

We focused on the unexpected phen promoted cyanation reaction, and optimized the reaction conditions. First, we screened several diamines for the catalysts of the cyanation (Table 2). Without a catalyst, the reaction did not proceed at all, and the starting material **1a** was recovered quantitatively (Entry 1). 4,7-Dichloro-1,10-phenanthroline (dcphen) could also be used for the cyanation, but the efficiency was lower than that of phen (Entry 2). In contrast, 3,4,7,8-tetramethylphenanthroline (tmphen), 4,7-dichlorophenanthroline (Ph-phen), 2,2'-bipyridyl derivatives, and *N,N'*-dimethylethylenediamine (DMEDA) were ineffective (Entries 3–8).

A problem of the reaction was that dehalogenation of the substrate competed with the desired cyanation. It was probably because the naphthyl radical generated from **1a** partially reacted with DMSO before the reaction with Et<sub>4</sub>NCN.<sup>11</sup> We assumed that a higher concentration would be better for the reaction. The effect of the concentration for the cyanation is summarized in Table 3. As expected, increasing the concentration of **1a** from 0.1 M to 0.3 M drastically suppressed the generation of the dehalogenated by-product **3a**, and increased the yield of **2a** to 55% (Entry 2). With 0.5 M of **1a**, the yield of **2a** was up to 60% (Entry 3). Under much higher concentration or neat conditions, the dehalogenation was efficiently suppressed, but the yield of **2a** decreased (Entries 4 and 5).

**Table 2** Diamine Promoted Cyanation of **1a**



Entry	Diamine	<b>2a</b> (%) <sup>a</sup>	<b>3a</b> (%) <sup>a</sup>	<b>1a</b> (%) <sup>a</sup>
1	None	N.D. <sup>b</sup>	N.D.	>99
2	dcphen <sup>c</sup>	23	20	N.D.
3	tmphen <sup>d</sup>	2	4	89
4	Ph-phen <sup>e</sup>	N.D.	2	94
5	bpy <sup>f</sup>	N.D.	2	96
6	dmbpy <sup>g</sup>	N.D.	3	96
7	dtbpy <sup>h</sup>	N.D.	2	92
8	DMEDA <sup>i</sup>	N.D.	3	92

<sup>a</sup>Determined by GC analysis with dodecane as an internal standard.

<sup>b</sup>Not detected.

<sup>c</sup>dcphen = 4,7-Dichloro-1,10-phenanthroline.

<sup>d</sup>tmphen = 3,4,7,8-Tetramethyl-1,10-phenanthroline.

<sup>e</sup>Ph-phen = 4,7-Diphenyl-1,10-phenanthroline.

<sup>f</sup>bpy = 2,2'-Bipyridyl.

<sup>g</sup>dmbpy = 4,4'-Dimethyl-2,2'-bipyridyl.

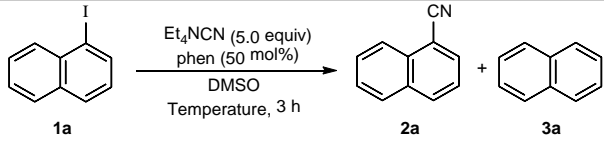
<sup>h</sup>dtbpy = 4,4'-Di-*tert*-butyl-2,2'-bipyridyl.

<sup>i</sup>DMEDA = *N,N'*-Dimethylethylenediamine.

During the course of further optimizations, it was revealed that the reaction was highly influenced by the reaction temperature

(Entries 6 and 7). When the reaction was performed at 130 °C, the yield of **2a** drastically increased (Entry 6). In this case, the amount of phen could be reduced to 20 mol% and **2a** was obtained in 78% isolated yield within 1 h. In contrast, **2a** was not obtained at 100 °C, meaning that precise control of the reaction temperature was quite significant for the reaction.

**Table 3** Effect of Concentration and Reaction Temperature



Entr y	Concc of <b>1a</b> (M)	Temp. (°C)	<b>2a</b> (%) <sup>a</sup>	<b>3a</b> (%) <sup>a</sup>	<b>1a</b> (%) <sup>a</sup>
1	0.1	150	48	47	N.D. <sup>b</sup>
2	0.3	150	55	13	N.D.
3	0.5	150	60	12	N.D.
4	1.0	150	58	9	N.D.
5	Neat	150	48	6	N.D.
6	0.5	130	71 (77) <sup>c</sup> (78) <sup>c,d</sup>	10 (10) <sup>c</sup>	N.D. (N.D.) <sup>c</sup>
7	0.5	100	N.D.	N.D.	95%

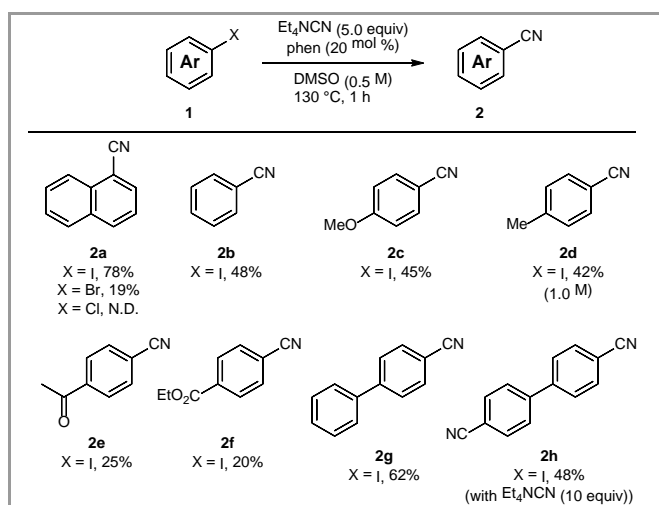
<sup>a</sup> Determined by GC analysis with dodecane as an internal standard.

<sup>b</sup> Not detected.

<sup>c</sup> Performed with 20 mol% of phen.

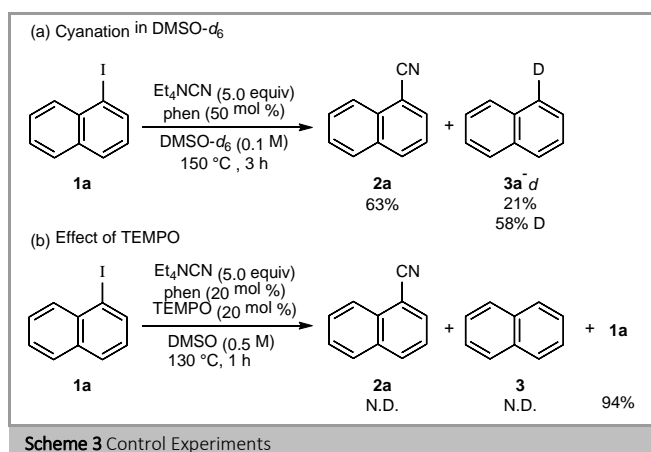
<sup>d</sup> Performed for 1 h. Isolated yield.

Under the optimized conditions, phen promoted cyanation of several aryl halides was conducted (Scheme 2).<sup>11</sup> With 1-bromonaphthalene, **2a** was obtained in 19% yield. The reaction using 1-chloronaphthalene did not give **2a** at all. Using iodobenzene, we obtained benzonitrile (**2b**) in 48% yield. Iodoarenes bearing electron-donating substituents, such as *p*-iodoanisole and *p*-iodotoluene, could be applicable for the reaction and the corresponding cyanated compounds **2c** and **2d** were obtained in 45% and 42% yield, respectively. The use of iodoarenes having electron-withdrawing groups, such as *p*-iodoacetophenone and ethyl 4-iodobenzoate, gave the cyanated compounds **2e** and **2f** in respective yields of 25% and 20%. In contrast, use of a  $\pi$ -extended precursor such as 4-iodo-1,1'-biphenyl gave a good result (**2g**, 62% yield). A sequential double cyanated product (**2h**) was readily obtained from 4,4'-diiodo-1,1'-biphenyl.



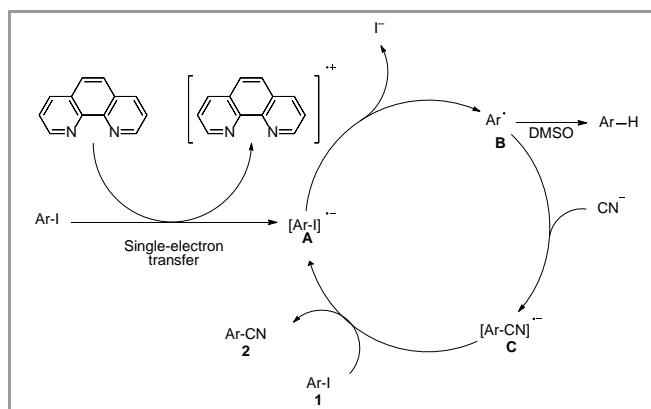
**Scheme 2** Cyanation of Several Aryl Halides under the Optimized Conditions. N.D. = not detected.

To get further insight on the reaction mechanism, we conducted two control experiments (Scheme 3). When the cyanation was carried out in DMSO-*d*<sub>6</sub>, **2a** was obtained in 63% yield with deuterated naphthalene **3a-d** (58% D) (Scheme 3 (a)). This result suggests that the major hydrogen donor of the reaction would be DMSO although there would be other hydrogen sources.<sup>12</sup> When the reaction was carried out in the presence of 20 mol % of TEMPO, the cyanation did not proceed at all (Scheme 3 (b)). Even with 5 mol % of TEMPO, only a trace amount of **2a** was obtained and quantitative amount of **1a** was recovered. These results suggest that the reaction would proceed via radical intermediates.<sup>13</sup>



**Scheme 3** Control Experiments

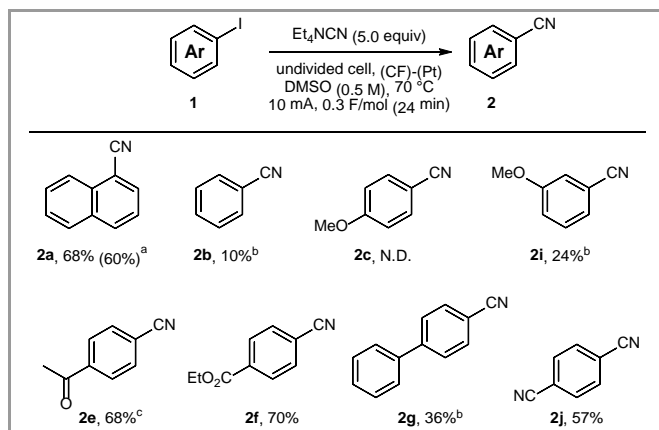
A plausible mechanism of the phen promoted cyanation reaction is illustrated in Figure 1. First, SET would occur from phen, bearing more positive reduction potential than aryl iodide (see, SI), to aryl iodide and a radical anion of the aryl iodide (**A**) should be generated. Then, elimination of iodide ( $I^-$ ) would give aryl radical **B**. When **B** reacts with DMSO, a dehalogenated product would be obtained. When **B** reacts with  $^-CN$ , a radical anion of aryl cyanide (**C**) would be generated. Then, SET would occur from **C** to **1** to afford aryl cyanide **2** with regenerated **A**.



**Figure 1** A plausible mechanism for phen promoted cyanation of aryl iodides.

As mentioned above, the cyanation reaction proceeded with a catalytic amount of phen, meaning that phen would work as a SET initiator on the first stage to generate radical anion **A**. We next examined the use of electroreduction instead of phen for the first generation of the radical anion species (Scheme 4).

Electricity was simply passed to the mixed solution of aryl iodide **1a** and Et<sub>4</sub>NCN (5.0 equiv) in DMSO at 70 °C. With 0.3 F/mol (to **1a**) of electricity, **1a** was consumed and the cyanated product (**2a**) was obtained in 68% yield.<sup>14</sup> Notably, the reaction proceeded with a catalytic amount of electricity. This result suggests that electricity would be required for the generation of aryl radical species, and the following catalytic cycle would proceed without electricity in the same way as with the phen promoted reaction. The protocol without any chemical initiator is operationally very simple and easy. In addition, it is advantageous that the reactions using electricity can be carried out at lower temperature than that of phen promoted reactions. Heating would be mainly required for the low solubility of Et<sub>4</sub>NCN to DMSO. Indeed, the electrochemical cyanation with Bu<sub>4</sub>NCN, which has a higher solubility to DMSO than Et<sub>4</sub>NCN, could be conducted at room temperature, and the desired product **2a** was obtained in 60% yield. The high temperature for the phen promoted reaction may be due to the higher energy requirement for the SET from phen to aryl iodide. In this case, electron-deficient aryl iodides gave better results than those of electron-rich aryl iodides, probably because electron-deficient aryl iodides would be readily reduced to generate aryl radical species. For instance, the reaction of 4-iodoanisole did not give the desired compound **2c**, and that of 3-iodoanisole gave the desired compound **2i** in 24% yield. In contrast, the reaction using electron-deficient aryl iodides, such as *p*-iodoacetophenone, ethyl 4-iodobenzoate, and 4-iodobenzonitrile, gave the desired products **2e**, **2f**, and **2j** in 68%, 70%, and 57% yields, respectively.



**Scheme 4** Electro-reductive Cyanation of Several Aryl Iodides. <sup>a</sup> Performed with Bu<sub>4</sub>NCN (7 equiv) at RT using (Pt)-(Pt) electrodes. <sup>b</sup> Performed with Et<sub>4</sub>NCN (7 equiv) at 90 °C. Amount of electricity passed was 0.5 F/mol. <sup>c</sup> Amount of electricity passed was 0.1 F/mol.

In conclusion, we have developed phen promoted cyanation reactions from aryl iodides and Et<sub>4</sub>NCN. Several aryl cyanides could be synthesized by the method. An electrochemical approach was also successful, and the cyanated products were obtained with a catalytic amount of electricity. Further investigations of the phen promoted reactions and electrochemical reactions are currently ongoing in our laboratory.

### Funding Information

This work was supported in part by JSPS KAKENHI Grant Numbers JP16K05695, JP16K05777, JP16H01155, and JP18H04415 in Middle Molecular Strategy.

### Acknowledgment

[Click here to insert acknowledgment text. Funding sources and grant numbers should be given above in the Funding Information section.](#)

### Supporting Information

YES (this text will be updated with links prior to publication)

### Primary Data

NO (this text will be deleted prior to publication)

### References and Notes

- (1) (a) Kleemann, A.; Engel, J.; Kutscher, B.; Reichert, D. *Pharmaceutical Substance: Synthesis Patents, Applications*, 4th Ed., Georg Thieme Verlag, Stuttgart, 2001. (b) Larock, R. C. *Comprehensive Organic Transformations: a Guide to Functional Group Preparations*, Wiley-VCH, Weinheim, 1989, pp 819. (c) Fleming, F. F.; Yao, L.; Ravikumar, P. C.; Funk, L.; Shook, B. C. *J. Med. Chem.* **2010**, *53*, 7902.
- (2) (a) Sandmeyer, T. *Chem. Ber.* **1884**, *17*, 1633. (b) Sandmeyer, T. *Chem. Ber.* **1884**, *17*, 2650. (c) Sandmeyer, T. *Chem. Ber.* **1885**, *18*, 1492. (d) Sandmeyer, T. *Chem. Ber.* **1885**, *18*, 1946. (e) Mo, F.; Qiu, D.; Zhang, Y.; Wang, J. *Acc. Chem. Res.* **2018**, *51*, 496.
- (3) (a) Rosenmund, K. W.; Struck, E. *Chem. Ber.* **1919**, *52*, 1749. (b) Koelsch, C. F.; Whitney, A. G. *J. Org. Chem.* **1941**, *6*, 795. (c) von Braun, J.; Manz, G. *Liebigs Ann. Chem.* **1931**, *488*, 111. (d) Connor, J. A.; Leeming, S. W.; Price, R. *J. Chem. Soc., Perkin Trans. 1* **1990**, 1127. (e) Callen, J. E.; Dornfeld, C. A.; Coleman, G. H. *Org. Synth.* **1948**, *28*, 34. (f) Wu, J. X.; Beck, B.; Ren, R. X. *Tetrahedron Lett.* **2002**, *43*, 387.
- (4) For reviews, see: (a) Anbarasan, P.; Schareina, T.; Beller, M. *Chem. Soc. Rev.* **2011**, *40*, 5049. (b) Sundermeier, M.; Zapf, A.; Beller, M. *Eur. J. Inorg. Chem.* **2003**, 3513. (c) Yan, G.; Zhang, Y.; Wang, J. *Adv. Synth. Catal.* **2017**, *359*, 4068. (d) Kim, J.; Kim, H. J.; Chang, S. *Angew. Chem., Int. Ed.* **2012**, *51*, 11948. (e) Wang, T.; Jiao, N. *Acc. Chem. Res.* **2014**, *47*, 1137. (f) Ping, Y.; Ding, Q.; Peng, Y. *ACS Catal.* **2016**, *6*, 5989.
- (5) For recent examples, see: (a) Zhang, S.; Neumann, H.; Beller, M. *Chem. - Eur. J.* **2018**, *24*, 67. (b) Xia, A.; Xie, X.; Chen, H.; Zhao, J.; Zhang, C.; Liu, Y. *Org. Lett.* **2018**, *20*, 7735. (c) Makaravage, K. J.; Shao, X.; Brooks, A. F.; Yang, L.; Sanford, M. S.; Scott, P. J. H. *Org. Lett.* **2018**, *20*, 1530. (d) Gan, Y.; Wang, G.; Xie, X.; Liu, Y. *J. Org. Chem.* **2018**, *83*, 14036. (e) Zhang, X.; Xia, A.; Chen, H.; Liu, Y. *Org. Lett.* **2017**, *19*, 2118. (f) Kristensen, S. K.; Eikeland, E. Z.; Taarning, E.; Lindhardt, A. T.; Skrydstrup, T. *Chem. Sci.* **2017**, *8*, 8094. (g) Kim, K.; Hong, S. H. *Adv. Synth. Catal.* **2017**, *359*, 2345. (h) Coombs, J. R.; Fraunhofer, K. J.; Simmons, E. M.; Stevens, J. M.; Wisniewski, S. R.; Yu, M. *J. Org. Chem.* **2017**, *82*, 7040. (i) Bag, S.; Jayarajan, R.; Dutta, U.; Chowdhury, R.; Mondal, R.; Maiti, D. *Angew. Chem., Int. Ed.* **2017**, *56*, 12538. (j) Skoch, K.; Cisarova, I.; Stepnicka, P. *Organometallics* **2015**, *34*, 1942. (k) Sharif, M.; Wu, X.-F. *RSC Adv.* **2015**, *5*, 21001. (l) Nasrollahzadeh, M.; Jaleh, B.; Fakhri, P.; Zahraei, A.; Ghadery, E. *RSC Adv.* **2015**, *5*, 2785. (m) Mishra, N. K.; Jeong, T.; Sharma, S.; Shin, Y.; Han, S.; Park, J.; Oh, J. S.; Kwak, J. H.; Jung, Y. H.; Kim, I. S. *Adv. Synth. Catal.* **2015**, *357*, 1293. (n) Cohen, D. T.; Buchwald, S. L. *Org. Lett.* **2015**, *17*, 202. (o) Zanon, J.; Klapars, A.; Buchwald, S. L. *J. Am. Chem. Soc.* **2003**, *125*, 2890.
- (6) For recent representative reports, see: (a) Zheng, S.; Yu, C.; Shen, Z. *Org. Lett.* **2012**, *14*, 3644. (b) Shu, Z.; Ji, W.; Wang, X.; Zhou, Y.; Zhang, Y.; Wang, J. *Angew. Chem., Int. Ed.* **2014**, *53*, 2186. (c) Dong, J.; Wu, Z.; Liu, Z.; Liu, P.; Sun, P. *J. Org. Chem.* **2015**, *80*, 12588. (d) Mishra, N. K.; Jeong, T.; Sharma, S.; Shin, Y.; Han, S.; Park, J.; Oh, J. S.; Kwak, J. H.; Jung, Y. H.; Kim, I. S. *Adv. Synth. Catal.* **2015**, *357*, 1293. (e) Okamoto, K.; Sakata, N.; Ohe, K. *Org. Lett.* **2015**, *17*, 4670. (f) Pawar, A. B.; Chang, S. *Org. Lett.* **2015**, *17*, 660. (g) Zhao, M.; Zhang, W.; Shen, Z. *J. Org. Chem.* **2015**, *80*, 8868. (h) Zhu, Y.; Li, L.; Shen, Z. *Chem. - Eur. J.* **2015**, *21*, 13246. (i) Zhu, Y.; Zhao, M.; Lu,

- W.; Li, L.; Shen, Z. *Org. Lett.* **2015**, *17*, 2602. (j) Liu, W.; Richter, S. C.; Mei, R.; Feldt, M.; Ackermann, L. *Chem. - Eur. J.* **2016**, *22*, 17958. (k) Takise, R.; Itami, K.; Yamaguchi, J. *Org. Lett.* **2016**, *18*, 4428. (l) Ogiwara, Y.; Morishita, H.; Sasaki, M.; Imai, H.; Sakai, N. *Chem. Lett.* **2017**, *46*, 1736. (m) Yan, Y.; Sun, S.; Cheng, J. *J. Org. Chem.* **2017**, *82*, 12888. (n) Yu, P.; Morandi, B. *Angew. Chem., Int. Ed.* **2017**, *56*, 15693. (o) Lv, S.; Li, Y.; Yao, T.; Yu, X.; Zhang, C.; Hai, L.; Wu, Y. *Org. Lett.* **2018**, *20*, 4994. (p) Shirsath, S. R.; Shinde, G. H.; Shaikh, A. C.; Muthukrishnan, M. *J. Org. Chem.* **2018**, *83*, 12305. (q) Yu, X.; Tang, J.; Jin, X.; Yamamoto, Y.; Bao, M. *Asian J. Org. Chem.* **2018**, *7*, 550. (r) Ueda, Y.; Tsujimoto, N.; Yurino, T.; Tsurugi, H.; Mashima, K. *Chem. Sci.* **2019**, *10*, 994.
- (7) (a) Dohi, T.; Morimoto, K.; Kiyono, Y.; Tohma, H.; Kita, Y. *Org. Lett.* **2005**, *7*, 537. (b) Dohi, T.; Morimoto, K.; Takenaga, N.; Goto, A.; Maruyama, A.; Kiyono, Y.; Tohma, H.; Kita, Y.; *J. Org. Chem.* **2007**, *72*, 109. (c) Yang, Y.; Zhang, Y.; Wang, J. *Org. Lett.* **2011**, *13*, 5608. (d) McManus, J.; Nicewicz, D. *J. Am. Chem. Soc.* **2017**, *139*, 2880.
- (8) (a) Petrillo, G.; Novi, M.; Garbarino, G.; Dell'Erba, C. *Tetrahedron* **1987**, *43*, 4625. (b) Novi, M.; Garbarino, G.; Petrillo, G.; Dell'Erba, C. *Tetrahedron* **1990**, *46*, 2205.
- (9) For representative examples, see: (a) Yanagisawa, S.; Ueda, K.; Taniguchi, T.; Itami, K. *Org. Lett.* **2008**, *10*, 4673. (b) Sun, C.; Li, H.; Yu, D.; Yu, M.; Zhou, X.; Lu, X.; Huang, K.; Zheng, S.; Li, B.; Shi, Z. *Nat. Chem.* **2010**, *2*, 1044. (c) Shirakawa, E.; Itoh, K.; Higashino, T.; Hayashi, T. *J. Am. Chem. Soc.* **2010**, *132*, 15537. (d) Liu, W.; Cao, H.; Zhang, H.; Zhang, H.; Chung, K. H.; He, C.; Wang, H.; Kwong, F. Y.; Lei, A. *J. Am. Chem. Soc.* **2010**, *132*, 16737. (e) Qiu, Y.; Liu, Y.; Yang, K.; Hong, W.; Li, Z.; Wang, Z.; Yao, Z.; Jiang, S. *Org. Lett.* **2011**, *13*, 3556. (f) Buden, M. E.; Guastavino, J. F.; Rossi, R. A. *Org. Lett.* **2013**, *15*, 1174. (g) Dewanji, A.; Murarka, S.; Curran, D. P.; Studer, A. *Org. Lett.* **2013**, *15*, 6102. (h) Leifert, D.; Daniliuc, C. G.; Studer, A. *Org. Lett.* **2013**, *15*, 6286. (i) Wertz, S.; Leifert, D.; Studer, A. *Org. Lett.* **2013**, *15*, 928. (j) Song, Q.; Zhang, D.; Zhu, Q.; Xu, Y. *Org. Lett.* **2014**, *16*, 5272. (k) Studer, A.; Curran, D. P. *Nat. Chem.* **2014**, *6*, 765. Hartmann, M.; Daniliuc, C. G.; Studer, A. *Chem. Commun.* **2015**, *51*, 3121. (l) Leifert, D.; Studer, A. *Org. Lett.* **2015**, *17*, 386. (m) Anton-Torrecillas, C.; Felipe-Blanco, D.; Gonzalez-Gomez, J. C. *Org. Biomol. Chem.* **2016**, *14*, 10620. (n) Jia, F.-C.; Xu, C.; Zhou, Z.-W.; Cai, Q.; Wu, Y.-D.; Wu, A.-X. *Org. Lett.* **2016**, *18*, 5232. (o) Zhang, L.; Yang, H.; Jiao, L. *J. Am. Chem. Soc.* **2016**, *138*, 7151. (p) Buden, M. E.; Bardagi, J. I.; Puiatti, M.; Rossi, R. A. *J. Org. Chem.* **2017**, *82*, 8325. (q) Taniguchi, T.; Naka, T.; Imoto, M.; Takeda, M.; Nakai, T.; Mihara, M.; Mizuno, T.; Nomoto, A.; Ogawa, A. *J. Org. Chem.* **2017**, *82*, 6647. (r) Barham, J. P.; Dalton, S. E.; Allison, M.; Nocera, G.; Young, A.; John, M. P.; McGuire, T.; Campos, S.; Tuttle, T.; Murphy, J. A. *J. Am. Chem. Soc.* **2018**, *140*, 11510. (s) Guo, Z.; Li, M.; Mou, X.-Q.; He, G.; Xue, X.-S.; Chen, G. *Org. Lett.* **2018**, *20*, 1684. (t) Shirakawa, E.; Hayashi, T. *Chem. Lett.* **2012**, *41*, 130. (u) Shirakawa, E.; Watabe, R.; Murakami, T.; Hayashi, T. *Chem. Commun.* **2013**, *49*, 5219. (v) Shirakawa, E.; Tamakuni, F.; Kusano, E.; Uchiyama, N.; Konagaya, W.; Watabe, R.; Hayashi, T. *Angew. Chem., Int. Ed.* **2014**, *53*, 521. (w) Ueno, R.; Ikeda, Y.; Shirakawa, E. *Eur. J. Org. Chem.* **2017**, *2017*, 4188. (x) Ikeda, Y.; Ueno, R.; Akai, Y.; Shirakawa, E. *Chem. Commun.* **2018**, *54*, 10471. (y) Kiriya, K.; Okura, K.; Tamakuni, F.; Shirakawa, E. *Chem. - Eur. J.* **2018**, *24*, 4519. (z) Okura, K.; Teranishi, T.; Yoshida, Y.; Shirakawa, E. *Angew. Chem., Int. Ed.* **2018**, *57*, 7186.
- (10) Shirakawa and Hayashi reported that their cross-coupling reaction did not proceed without *MOT*-Bu (see: ref 9(c)).
- (11) **Synthesis of 2a with phen.** A solution of 1-iodonaphthalene (127 mg, 0.50 mmol), Et<sub>4</sub>NCN (391 mg, 2.50 mmol), and 1,10-phenanthroline (18.2 mg, 0.1 mmol) in DMSO (1 mL) was stirred at 130 °C for 1 h. Into the resulting mixture was added H<sub>2</sub>O (15 mL), and the mixture was extracted with EtOAc (3 × 5 mL). The combined organic phase was dried over MgSO<sub>4</sub>, filtrated, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexane/EtOAc 30:1) to give 1-naphthonitrile (**2a**) as yellow oil (59.5 mg, 0.39 mmol, 78%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.53 (t, *J* = 7.8 Hz, 1H), 7.63 (t, *J* = 7.6 Hz, 1H), 7.70 (t, *J* = 7.9 Hz, 1H), 7.87–7.96 (m, 2H) 8.08 (d, *J* = 7.9 Hz, 1H), 8.24 (d, *J* = 7.9 Hz, 1H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 110.0, 117.7, 124.8, 125.0, 127.4, 128.5, 128.6, 132.2, 132.5, 132.8, 133.2; IR (neat) 3061, 2222, 1591, 1512, 1375 cm<sup>-1</sup>.
- (12) Caminos, D. A.; Garro, A. D.; Soria-Castro, S. M.; Alicia B. Peñeñory, A. B. *RSC Adv.* **2015**, *5*, 20058.
- (13) It is known that the addition of TEMPO suppressed S<sub>RN</sub>1-type reactions (see ref 9(a), 9(d), and 9(e)).
- (14) **Electrochemical synthesis of 2a.** The electro-reduction was carried out in a 10 mL vial equipped with a carbon felt anode (Nippon Carbon JF-20-P7, ca. 320 mg, dried at 250 °C/1 mmHg for 1 h prior to use) and a platinum plate cathode (12 mm × 3 mm). The vial was charged with a solution of 1-iodonaphthalene (127 mg, 0.50 mmol) and tetraethylammonium cyanide (391 mg, 2.50 mmol) in DMSO (1 mL). A constant current (10 mA, 0.3 F/mol) was supplied at 70 °C with magnetic stirring. Into the resulting mixture was added H<sub>2</sub>O (15 mL), and the mixture was extracted with EtOAc (3 × 5 mL). The combined organic phase was dried over MgSO<sub>4</sub>, filtrated, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexane/EtOAc 30:1) to give 1-naphthonitrile (**2a**) as yellow oil (52.1 mg, 0.34 mmol, 68%).