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S. J. Connon, M. O. Senge *et al.*
Conformational control of nonplanar free base porphyrins: towards bifunctional catalysts of tunable basicity

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COMMUNICATION

Copper-Catalyzed Arylation of Polycyclic Aromatic Hydrocarbons by P=O Group

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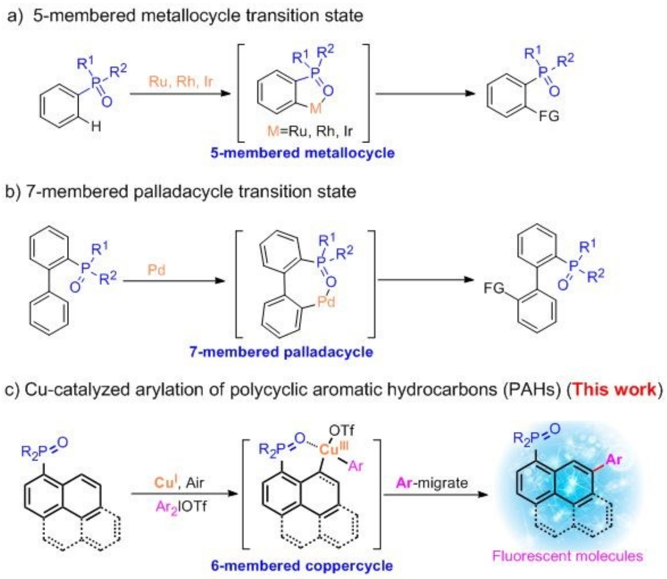
The first example of a directed and regioselective arylation of the polycyclic aromatic hydrocarbons (PAHs) by using a P=O directing group is reported herein. The protocol uses cheap copper catalyst, and results in a breakthrough meta-selective C–H functionalization of arylphosphine oxides compounds. Substrates with potential fluorescence properties, for example pyrene and fluoranthene, were successfully arylated under the system, thus achieving an efficient modification of fluorescent molecules containing P = O functional group.

Transition-metal-catalyzed C–H functionalization has become one of the most effective and convenient synthesis strategies at present for the synthesis of organic molecules.[1] An approach that has received widespread attention in this area is the use of directing groups whose precise guidance opens up a new avenue for the modification of original molecular framework in a defined and predictable fashion. In recent years, great effort has been devoted in the area of modification of aryl compounds by using directing groups such as heterocycles,[2] anilides,[3] amides,[4] carboxylic acid[5] and ketones[6] Most of these reports achieved activation of the C–H bond ortho to the directing group via the formation of a stable 5 or 6 membered cyclometalated intermediate. In 2009, the pioneering work of Gaunt and co-workers reported the *meta*-arylation with acetanilide as the directing group on the aryl ring, in a copper catalytic manifold.[7] This reaction established a new activation mode in the field of C–H bond activation.[8] Following this concept, we wanted to achieve the meta-functionlisation of arylphosphine oxides. This goal would be of significant interest to the synthetic community as it would provide tools for the late stage functionalisation of phosphorus containing ligands[9] and fluorescent molecules.[10] The work of Shibata in 2012 confirmed that phosphine oxides could be used as directing groups for ortho-C–H bond functionalization.[11]



Scheme1. Strategies of functionalizations directed by aryl P = O group

Since then, several methods for the direct functionalisation of arylphosphine oxides have been reported.[12] It has been shown that the transition metal can coordinate with the oxygen atom in the arylphosphine oxides and this leads to the formation of five-membered[13] or seven-membered cyclometalated intermediates,[14],which deliver the corresponding products with high regioselectivity (**Scheme 1a** and **1b**). These developments have made the modification of organophosphorus compounds more readily attainable, including the modification of synthetically relevant phosphorous containing ligands. Nevertheless, The reactions still rely on precious metal catalyst such as Ru, Rh, Ir, Pd, and only yielding functionalisation for specific C–H bonds. As a consequence, it is imperative to find an alternative low-cost metal catalyst as well as a new catalytic model for the C–H activation of arylphosphine oxides. Furthermore, the modification of new substrates beyond traditional phenyl or biphenyl phosphorus sources is highly desirable considering the unique fluorescence properties of both polycyclic aromatics as well as phosphine oxide containing compound.[15] The installation of a phosphine oxide

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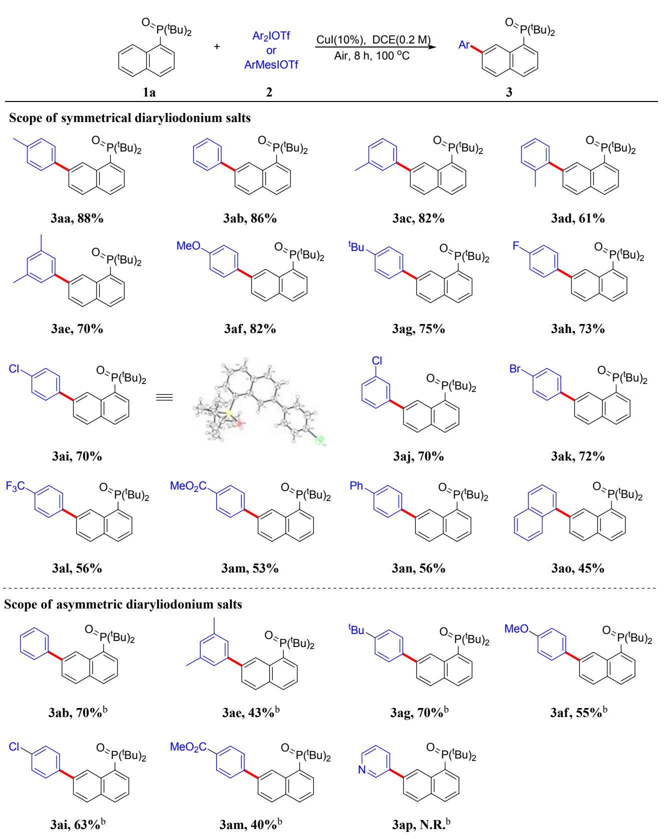
directing group on polycyclic aromatics and the achieving subsequent modification by C–H bond functionalization would therefore be of great significance.[10a, 10b] Previously, You and co-workers reported the palladium catalysed C_7–H arylation of naphthamides.[16] Herein, by using a cheaper copper catalyst, we are able to realize the C_7–H arylation of naphthylphosphine oxides with diaryliodonium triflate salts (**Scheme 1c**). This achievement not only provides a new activation mode for arylphosphine oxide substrates, but also yields an important access toward enhanced scope of compounds with improved photophysical properties.

After detailed screening, the optimised reaction conditions were found to be; CuI (10 mol%) as catalyst in DCE, 1.0 equiv 1-$P(O)(^tBu)_2$ naphthalene (**1a**) and 1.5 equiv di(*p*-methylphenyl)iodonium triflate salt at 100 °C under air (for details see SI). In order to verify the generality of the reaction, the scope of diaryliodonium triflate salts was first explored. As shown in **Table 1**, symmetric diaryliodonium salts bearing electron-donating groups were applied, and the desired C_7–H arylation product were delivered in 61%-88% yield (**3aa**, **3ac**, **3ae**-**3ag**). Diphenyliodonium triflate salt (**2b**) could also be converted into corresponding product in 86% yield (**3ab**). It should be noted that the reaction showed moderate sensitivity to the steric effect of the substrates, with di-*o*-methylbenzene triflate salts (**2d**) giving a slightly lower yield of the corresponding product compared with the *para* and *meta*-variants (**3ad**). The reaction also showed high efficiency when diaryliodonium triflate bearing electron-withdrawing groups such as halogens, CF_3, CO_2Me and the corresponding products were obtain in 56%-73% yield (**3ah**-**3an**). The structure of **3ai** was unambiguously confirmed by X-ray analysis. The diaryliodonium triflate salt contained 1-naphthyl could also be tolerated in this reaction and the product was delivered in 46% yield (**3ao**). In addition, asymmetric diaryliodonium triflate salts were also tested in the system. We were pleased to find that the reaction showed complete selectivity toward the mono-substituted aromatic component and the products were produced in 40%-70% yield (**3ab**, **3ae**, **3ag**, **3af**, **3ai**, **3am**) (**Table 1,** bottom). At the current stage of development, the reaction couldn't proceed when asymmetric diaryliodonium triflate salts containing pyridine group (**3ap**).

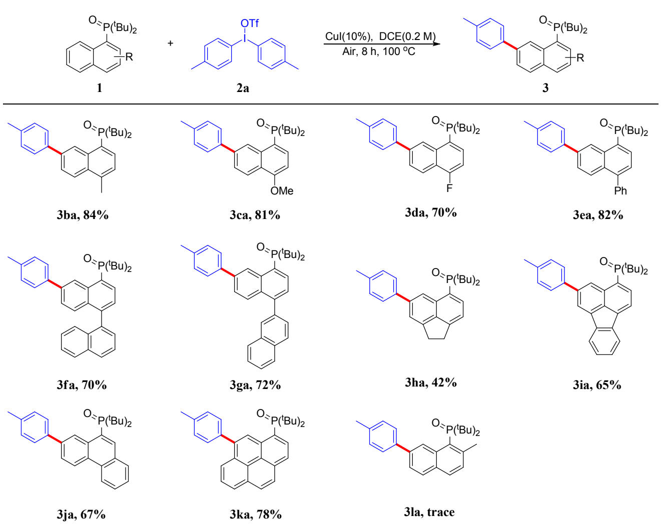
Table 1. Substrate scope of the diaryliodonium salts[a]



[a] Reaction conditions: **1a** (0.1 mmol, 1.0 equiv), **2** (0.15 mmol, 1.5 equiv), CuI (0.01 mmol, 10% mol) in DCE at 100 °C for 8 h under air. [b] Using ArMesIOTf instead of Ar_2IOTf. Mes = mesitylene. N.R. = no reaction.

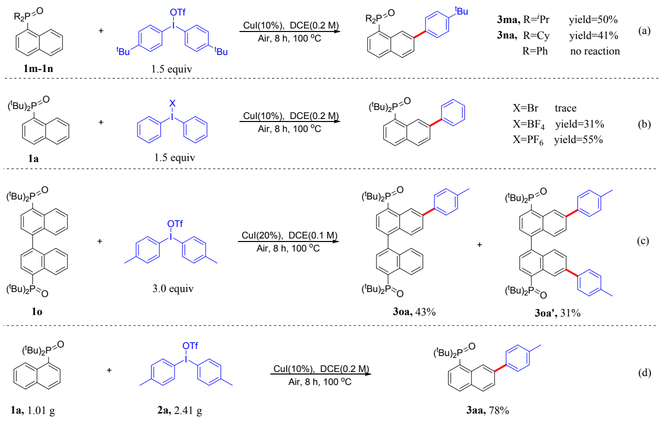
Following this, we tested the scope of phosphorus component, using di(*p*-methylphenyl)iodonium triflate salt as the aryl source. The product could be obtained in high yields wherever naphthalene ring bearing an etlecron-donating group (Me or OMe) (**Table 2**, **3ba**-**3ca**) or halogen and electron-withdrawing group (F, phenyl or naphthyl) (**3da**-**3ga**). Further, different phosphorus environments, such as $P(O)(^tBu)_2$, could also be used as suitable directing groups and afforded the corresponding arylated products in moderate to high yields (**3ha**-**3ka**). Only trace amount of product was observed when using steric bulky 1-$P(O)(^tBu)_2$ unit as the directing group. (**3la**).

Table 2. Substrate scope of the fused rings bearing $P(O)(^tBu)$ directing group[a]



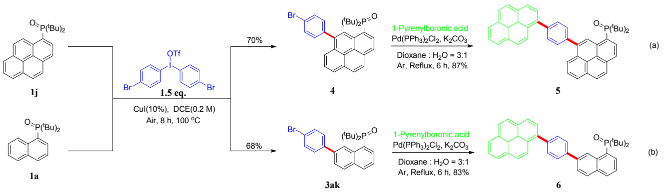
[a] Reaction conditions: **1** (0.1 mmol, 1.0 equiv), **2a** (0.15 mmol, 1.5 equiv), CuI (0.01 mmol, 10% mol) in DCE at 100 °C for 8 h under air.

To further explore the applicability of this reaction, more compounds were subjected to the optimised reaction conditions. We could obtain the desired product in moderate yields when using isopropyl and cyclohexyl group based phosphorus oxides (**3ma**-**3na**). However, the phenyl based variant failed to yield the product. (**Scheme 2a**). Then the counter-ion of the diaryliodonium salts was examined. (Br^-, BF_4^-, and PF_6^-) were tested and the desired product were produced in significantly lower yield (**Scheme 2b**). Following this, substrate **1o** bearing two phosphorus directing groups was used in the reaction. With slight modifications to the reaction conditions, a mixture of the mono and bis arylated compounds **3oa** and **3oa'** were obtained in 43% and 31% yields respectively (**Scheme 2c**). In addition, we were pleased to find that the reaction was amenable to increased scale with **3aa** being isolated in 78% yield on gram-scale (**Scheme 2d**).



Scheme 2. Extension of reaction scope and gram scale experiment

Considering the fact that several arylphosphine oxides exhibit fluorescence, especially when combined with the pyrene unit, we synthesized substrate **1j** with a pyrene functional group to investigate its potential application in our system (**Scheme 3a**). Taking advantage of the tolerance of the aryl bromides in our system, compound **4** was delivered in 70% yield which can be further modified by Suzuki coupling reaction, thus the extended aromatic molecule **5**. Meanwhile, compound **6** with similar structure was also synthesized from same approach. (**Scheme 3b**).



Scheme 3. Further synthesis of potential fluorescent molecules on the basis of reaction

Subsequently, the photophysical properties of the compounds (including the substrates and product) containing the pyrene unit were investigated (**Table 3** and **Figure 1**). The absorption band of the substrate **1a** ranges from 230 to 330 nm and only includes two absorption peaks. Instead, compounds containing pyrene unit (**1k**, **3ka**, **5**, **6**) exhibit more red-shifted absorptions (240–400 nm) due to their extended π-conjugated skeleton. At the same time, when compared with the substrate **1a**, the compounds bearing a pyrene unit emit violet to deep blue fluorescence and the emission wavelength are generally red shifted by about 50-100 nm because of the strong intramolecular charge-transfer effect. Fluorescence lifetimes (τ_F) of compounds **1a**, **1k**, **3ka**, **5** and **6** were also determined and the results shown in **Table 3**. Interestingly, a significant change of fluorescence lifetimes was observed between the **1k** and its arylated variants. We believe that the fluorescence properties of these compounds would provide more choices for chemists in screening fluorescent molecules.

Table 3. Photophysical properties of **1a**, **1k**, **3ka**, **5** and **6**

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Compounds	$\lambda_{abs}{}^a$ (nm)	$\lambda_{em}{}^b$ (nm)	$\tau_F{}^c$ (ns)
1a	236, 291	333	6.88
1k	246, 270, 281, 334, 351, 378	380	26.16
3ka	230, 248, 286, 341, 355, 382	390	8.75
5	246, 285, 346, 354	448	3.42
6	244, 279, 348	407	1.94

[a] Absorption maxima in DCM (1.0 × 10^{-5} M). [b] Emission maxima in DCM (1.0 × 10^{-5} M). [c] Photoluminescence lifetime in neat film

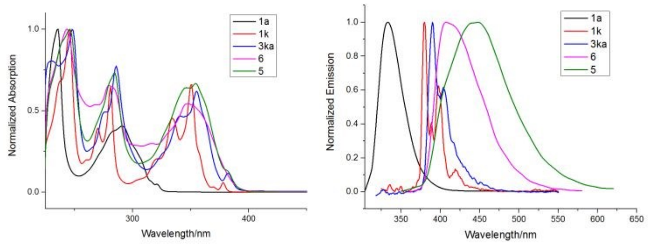
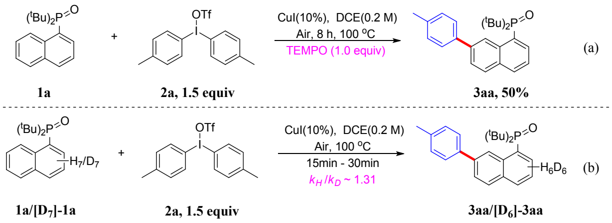


Figure 1. (left) Absorption and (right) emission spectra of **1a**, **1k**, **3ka**, **5** and **6** in DCM (1.0 × 10^{-5} M).

To gain further insight into the mechanism of this reaction. We ran the standard reaction with the addition of 1 equiv of 2,2,6,6-tetramethylpiperidinooxy (TEMPO) as a radical scavenger. The desired product was obtained in 50% which suggests that radical species are not involved in this transformation (**Scheme 4a**). Meanwhile, the intramolecular KIE experiment presents a small K_H/K_D value (1.31) (**Scheme 4b**), which indicates that the activation of C–H bond at the C7-position of naphthalene ring may not involved in the rate-determining step. Based on these results and previous reports on Cu catalyzed arylation, a tentative reaction mechanism was proposed in the supporting information. (it's shown in **7.3** of the table of content)



Scheme 4. Mechanism experiment

In conclusion, we have reported a new activation mode for arylphosphine oxides, in which the C_7–H bond of naphthalene ring and other polycyclic aromatics which own potential fluorescence properties were arylated by a cheap copper catalyst under simple reaction conditions. This reaction provides a new method to potentially modulate the photophysical properties of PAH's and has been shown to be tolerant of several relevant functional groups. The reaction displays excellent regioselectivity and provides a new pathway toward the modification of arylphosphine oxide compounds.

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Conflicts of interest

There are no conflicts to declare.

Notes and references

1 (a) K.-J. Jiao, Y.-K. Xing, Q.-L. Yang, H. Qiu, T.-S. Mei, *Acc. Chem. Res.,* 2020, **53**, 300; (b) Q. Shao, K. Wu, Z. Zhuang, S. Qian, J.-Q. Yu, *Acc. Chem. Res.*, 2020, **53**, 833; (c) S. Rej, N. Chatani, *Angew. Chem. Int. Ed.*, 2019, **58**, 8304; (d) Y. Xu, G.-B. Dong, *Chem. Sci.*, 2018, **9**, 1424; (e) J. A. Labinger, *Chem. Rev.*, 2017, **117**, 8483; (f) M. Parasram, V. Gevorgyan, *Acc. Chem. Res.*, 2017, **50**, 2038; (g) C. Sambiagio, D. Schönbauer, R. Blieck, T. Dao-Huy, G. Pototschnig, P. Schaaf, T. Wiesinger, M. F. Zia, J. Wencel-Delord, T. Besset, B. U. W. Maes, M. Schnürch, *Chem. Soc. Rev.*, 2018, **47**, 6603; (h) C. Wang, L. Luo, H. Yamamoto, *Acc. Chem. Res.*, 2016, **49**, 193.

2 (a) P. Ramírez-López, A. Ros, B. Estepa, R. Fernandez, B. Fiser, E. Gomez-Bengoa, J. M. Lassaletta, *ACS Catal.*, 2016, **6**, 3955; (b) P. Ramírez-López, A. Ros, A. Romero-Arenas, J. Iglesias-Sigüenza, R. Fernandez, J. M. Lassaletta, *J. Am. Chem. Soc.*, 2016, **138**, 12053; (c) T.-J. Gong, M.-Y. Xu, S.-H. Yu, C.-G. Yu, W. Su, X. Lu, B. Xiao, Y. Fu, *Org. Lett.*, 2018, **20**, 570; (d) D. Kalyani, N. R. Deprez, L. V. Desai, M. S. Sanford, *J. Am. Chem. Soc.*, 2005, **127**, 7330; (e) D. W. Robbins, T. A. Boebel, J. F. Hartwig, *J. Am. Chem. Soc.*, 2010, **132**, 4068; (f) M. Shang, M.-M. Wang, T. G. Saint-Denis, M.-H. Li, H.-X. Dai, J.-Q. Yu, *Angew. Chem. Int. Ed.*, 2017, **56**, 5317.

3 (a) J. Park, S. Chang, *Angew. Chem. Int. Ed.*, 2015, **54**, 14103; (b) S.-D. Yang, B.-J. Li, X.-B. Wan, Z.-J. Shi, *J. Am. Chem. Soc.*, 2007, **129**, 6066; (c) S. Grélaud, P. Cooper, L. J. Feron, J. F. Bower, *J. Am. Chem. Soc.*, 2018, **140**, 9351.

4 (a) M. Maraswami, S. Pankajakshan, G. Chen, T. P. Loh, *Org. Lett.*, 2017, **19**, 4223; (b) Y. Kommagalla, K. Yamazaki, T. Yamaguchi, N. Chatani, *Chem. Commun.*, 2018, **54**, 1359; (c) A. Obata, Y. Ano, N. Chatani, *Chem. Sci.*, 2017, **8**, 6650.

5 (a) C.-P. Chen, P. Liu, J.-H. Tang, G.-D. Deng, X.-M. Zeng, *Org. Lett.*, 2017, **19**, 2474; (b) E. Erbing, A. Sanz-Marco, A. Vázquez-Romero, J. Malmberg, M. J. Johansson, E. Gómez-Bengoa, B. Martín-Matute, *ACS Catal.*, 2018, **8**, 920; (c) G.-Y. Tan, Q.-L. You, J.-B. Lan, J.-S. You, *Angew. Chem. Int. Ed.*, 2018, **57**, 6309; (d) R. Giri, N. Maugel, J.-J. Li, D.-H. Wang, S. P. Breazzano, L. B. Saunders, J.-Q. Yu, *J. Am. Chem. Soc.*, 2007, **129**, 3510.

6 (a) V. Lanke, K. R. Bettadapur, K. R. Prabhu, *Org. Lett.*, 2016, **18**, 5496; (b) J.-C. Xu, Y. Liu, Y. Wang, Y.-J. Li, X.-H. Xu, Z. Jin, *Org. Lett.*, 2017, **19**, 1562; (c) B. Zhang, H.-W. Wang, Y.-S. Kang, P. Zhang, H.-J. Xu, Y. Lu, W.-Y. Sun, *Org. Lett.*, 2017, **19**, 5940; (d) E. Tan, O. Quinonero, M. E. D. Orbe, A. M. Echavarren, *ACS Catal.*, 2018, **8**, 2166; (e) P. Gandeepan, K. Parthasarathy, C.-H. Cheng, *J. Am. Chem. Soc.*, 2010, **132**, 8569.

7 R. J. Phipps, M. J. Gaunt, *Science*, 2009, **323**, 1593.

8 (a) M. Bera, S. Agasti, R. Chowdhury, R. Mondal, D. Pal, D. Maiti, *Angew. Chem. Int. Ed.*, 2017, **56**, 5272; (b) P. Wang, M. E. Farmer, J.-Q. Yu, *Angew. Chem. Int. Ed.*, 2017, **56**, 5125; (c) M. T. Mihal, G. R. Genov, R. J. Phipps, *Chem. Soc. Rev.*, 2018, **47**, 149; (d) B. Chen, X.-L. Hou, Y.-X. Li, Y.-D. Wu, *J. Am. Chem. Soc.*, 2011, **133**, 7668; (e) Y.-Q. Yang, R.-R. Li, Y. Zhao, D.-B. Zhao, Z.-Z. Shi, *J. Am. Chem. Soc.*, 2016, **138**, 8734.

9 (a) G.-Q. Xu, C. H. Senanayake, W.-J. Tang, *Acc. Chem. Res.*, 2019, **52**, 1101; (b) D. J. Durand, N. Fey, *Chem. Rev.*, 2019, **119**, 6561; (c) A. L. Clevenger, R. M. Stolley, J. Aderibigbe, J. Louie, *Chem. Rev.*, 2020, **120**, 6124; (d) A. Cabré, A. Riera, X. Verdaguer, *Acc. Chem. Res.*, 2020, **53**, 676.

10 (a) L.-Q. Qiu, W. Hu, D. Wu, Z. Duan, F. Mathey, *Org. Lett.*, 2018, **20**, 7821; (b) G. Mallesham, C. Swetha, S. Niveditha, M. E. Mohanty, N. J. Babu, A. Kumar, K. Bhanuprakash, V. J. Rao, *J. Mater. Chem. C*, 2015, **3**, 1208; (c) X.-Y. Chai, J. Xiao, M. Li, C.-M. Wang, H.-Y..An, C. Li, Y.-T. Li, D.-Z. Zhang, X.-Y. Cui, T. Wang, *Chem. Eur. J.*, 2018, **24**, 14506.

11 S. Takebayashi, T. Shibata, *Organometallics*, 2012, **31**, 4114.

12 (a) Z. Zhang, P. H. Dixneuf, J. F. Soulé, *Chem. Commun.*, 2018, **54**, 7265. (b) Y.-Q. Yang, X.-D. Qiu, Y. Zhao, Y.-C. Mu, Z.-Z. Shi, *J. Am. Chem. Soc.*, 2016, **138**, 495; (c) T. Wang, L.-Y. Zhou, Y.-Q. Yang, X.-H. Zhang, Z.-Z. Shi, Y.-D. Wu, *Org. Lett.*, 2018, **20**, 6502; d) X.-H. Hu, X.-F. Yang, T. P. Loh, *Angew. Chem. Int. Ed.*, 2015, **54**, 15535; (e) L.-Y. Chan, L. Cheong, S. Kim, *Org. Lett.*, 2013, **15**, 2186; (f) B. C. Chary, S. Kim, Y. Park, J. Kim, P. H. Lee, *Org. Lett.*, 2013, **15**, 2692.

13 (a) Y. S. Jang, M. Dieckmann, N. Cramer, *Angew. Chem. Int. Ed.*, 2017, **56**, 15088; (b) Y. S. Jang, Ł. Woźniak, J. Pedroni, N. Cramer, *Angew. Chem. Int. Ed.*, 2018, **57**, 12901; (c) D.-B. Zhao, C. Nimphius, M. Lindale, F. Glorius *Org. Lett.*, 2013, **15**, 4504; (d) Y. Unoh, T. Satoh, K. Hirano, M. Miura, *ACS Catal.*, 2015, **5**, 6634; (e) Y. Unoh, Y. Hashimoto, D. Takeda, K. Hirano, T. Satoh, M. Miura, *Org. Lett.*, 2013, **15**, 3258; (f) C.-S. Wang, P. H. Dixneuf, J. F. Soulé, *ChemCatChem*, 2017, **9**, 3117; (g) L.-J. Gu, C. Jin, R. Wang, H.-Y. Ding, *ChemCatChem*, 2014, **6**, 1225; (h) J. Mo, S. Lim, S. Park, T. Ryu, S. Kim, P. H. Lee, *RSC Adv.*, 2013, **3**, 18296; (i) B. C. Chary, S. Kim, *Org. Biomol. Chem.*, 2013, **11**, 6879;(j) Z. Liu, J.-Q. Wu, S.-D. Yang, *Org. Lett.*, 2017, **19**, 5434.

14 (a) Y.-N. Ma, S.-X. Li, S.-D. Yang, *Acc. Chem. Res.* 2017, **50**, 1480; (b) S.-X. Li, Y.-N. Ma, S.-D. Yang, *Org. Lett.*, 2017, **19**, 1842; (c) Y.-N. Ma, M.-X. Cheng, S.-D. Yang, *Org. Lett.*, 2017, **19**, 600; (d) C. Li, X.-Y. Qiang, Z.-C. Qi, B.-Cao, J.-Y. Li, S.-D. Yang, *Org. Lett.*, 2019, **21**, 7138.

15 (a) S. Takahashi, K. Hanaoka, Y. Okubo, H. Echizen, T. Ikeno, T. Komatsu, T. Ueno, K. Hirose, M. Iino, T. Nagano, Y. Urano, *Chem. Asian J.*, 2020, **15**, 524; (b) E. Regulska, H. Ruppert, F. Rominger, C. Romero-Nieto, *J. Org. Chem.*, 2020, **85**, 1247; (c) P. Hindenberg, F. Rominger, C. Romero-Nieto, *Chem. Eur. J.*, 2019, **25**, 13146; (d) S. Kasthuri, S. Kumar, S. Raviteja, B. Ramakrishna, S. Maji, N. Veeraiah, N. Venkatramaiah, *Applied Surface Science*, 2019, **481**, 1018; (e) X. Feng, C.-X. Qi, H.-T. Feng, Z. Zhao, H. H. Y. Sung, L. D. Williams, R. T. K. Kwok, J. W. Y. Lam, A.-J. Qin, B.-Z. Tang, *Chem. Sci.*, 2018, **9**, 5679; (f) X.-M. Chang, Z.-X. Zhou, C.-D. Shang, G. Wang, Z.-L. Wang, Y.-Y. Qi, Z.-Y. Li, H. Wang, L.-P. Cao, X.-P. Li, Y. Fang, P. J. Stang, *J. Am. Chem. Soc.*, 2019, **141**, 1757; (g) K. Katayama, I. Kawajiri, Y. Okano, J. I. Nishida, T. Kawase, *ChemPlusChem*, 2019, **84**, 722.

16 M. Zhang, A.-Q. Luo, Y. Shi, R.-C. Su, Y.-D. Yang, J.-S. You, *ACS Catal.*, 2019, **9**, 11802.

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The copper-catalyzed regioselective arylation of the polycyclic aromatic hydrocarbons (PAHs) with potential fluorescence properties by P=O group has been performed.