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Electrochemical Regioselective Phosphorylation of Nitrogen-Containing Heterocycles and Related Derivatives

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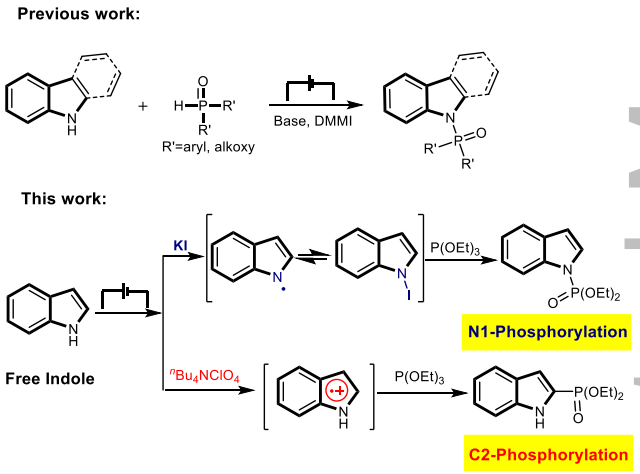
Abstract. The site-selective functionalization of biologically important nitrogen-containing heterocycles and related derivatives remains a challenging and important task. We report herein on the direct regiodivergent N1/C2 phosphorylation of free indole derivatives. Cyclic voltammograms and EPR data indicate that by utilizing different electrolyte-mediated anodic oxidation to generate different active indole species, a diverse collection of N1 and C2 phosphorylation products could be obtained in moderate to high yields under exogenous-oxidant-free and metal-catalyst-free electrochemical conditions. In addition, N-P coupling was also found to be compatible with various alkylamines.

Keywords: Electrochemical Oxidation; Free Indoles; Regioselectivity; N1/C2 Phosphorylation

Indoles and their partially saturated derivatives represent an important class of N-containing heterocycles and are basic constituents of numerous natural products, biologically active alkaloids and agrochemicals.[1] The indole ring is present in 24 currently marketed pharmaceutical products, making it the fourth most prevalent heteroaromatic ring.[2] This key heterocyclic core is also widely used in both organic synthesis and in material science.[3] Due to their characteristic properties, the functionalization of indoles has attracted considerable interest and direct C−H/N-H activation has become one of the most powerful strategies for the functionalization of indoles.[4] Numerous processes have been developed for modifying the indole structure, among which the N1, C2 and C3 positions have proven to be the main reactive sites.[5] Regarding reaction selectivity, the most feasible approaches involve blocking a specific position or the use of auxiliary groups. Although significant progress has been made, the selectivity and efficiencies of these strategies still leave room for improvement due to the similar reactivity of N-H/C-H bonds. Only a few examples of systems that allow a reaction-condition-dependent switch between C2, C3, and other positions on free indoles have been reported,[6] but reaction-condition-controlled selective N1 and C2 functionalization of free indoles remains relatively unexplored. As a result, the straightforward and simple routes for the N-H/C-H region-switchable functionalization of free indoles continues to be a highly attractive challenge.



Scheme 1. Electrochemical Oxidative Regioselective Phosphorylation of Free Indoles.

Electrochemical oxidation is recognized as an efficient and environmentally benign synthetic strategy and has attracted significant interest.[7] Processes have also been developed for the functionalization of indoles aided by electrochemical oxidation (Scheme 1).[8] Electrosynthesis could be used to achieve electron transfer between the electrodes and substrates or catalysts, thus avoiding the use of excess exogenous oxidants and thus, the generation of waste products. It is well known that supporting electrolytes are necessary for increasing the conductivity of organic systems in electrosynthesis, but their potential application in mediating the divergent activity of substrates has not been fully

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developed.[9] We hypothesized that the use of different electrolytes would lead to the production of different types of intermediates in the electrochemical oxidation of indoles (Scheme 1).

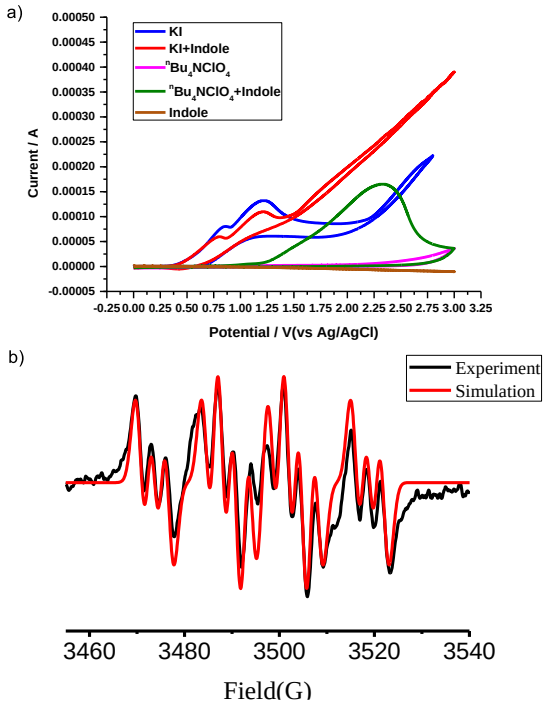

Figure 1. a) Cyclic voltammograms of different electrolytes and free indole. b) EPR spectrum of the reaction mixture containing KI and free indole in CH_3CN at room temperature under electric conditions with DMPO as a free radical scavenger.

With this in mind, we investigated the redox properties of free indoles in cyclic voltammetry in different electrolytes. Using ^{n}Bu$_4$NClO$_4$ as the electrolyte (Figure 1a), the cyclic voltammograms showed irreversible oxidation waves for free indole due to the electron-rich nature of the indole ring. This result indicates that free indole could be oxidized by the anode with the generation of a radical-cation intermediate. However, when ^{n}Bu$_4$NClO$_4$ was replaced with KI, no oxidation peak was observed for free indole, and iodide potassium exhibited a dual oxidation peak at 0.07V and 0.46V versus Ag/Ag+, respectively. At the same time, EPR spectroscopy were also performed in an attempt to detect a radical intermediate with the addition of the free radical spin-trapping agent 5, 5-dimethyl-1-pyrroline N-oxide (DMPO) (Figure 1b). An EPR signal corresponding to an N-centered radical species was observed in the standard reaction and this was confirmed by computer simulation. These results indicate that free indole could also be oxidized to generate an N-centered radical intermediate, which was different from the typically produced radical-cation intermediate. The N-centered radical arose from the reversible homolytic cleavage of an N-iodo intermediate. As shown in Scheme 1, since the reactive sites of the free indole could be tuned by the use of different electrolytes, the desired N-H/C-H functionalization would be expected to occur with a high degree of selectivity.

Based on the above results, triethyl phosphite was then added to capture the intermediates. To our delight, the indole N1 and C2 phosphorylation product **3a** and **4a** were indeed obtained. Both N1 and C2 phosphoindoles represent an important class of organophosphorus compounds, which are found not only in various biologically active compounds, but also have widespread applications in the fields of material science and organic synthesis as ligands.[10] Jin and Liu [8a] recently reported on the electrochemical oxidative dehydrogenative phosphorylation of N-heterocycles with P(O)-H compounds, which significantly simplified the N-P coupling process (Scheme 1). However, an equivalent amount of base was required in their reaction and diethyl phosphite was tolerated, but afforded the corresponding product in poor yield. Therefore, this novel electrochemical oxidative cross-coupling reaction for the synthesis of phosphorus-containing indoles prompted us to investigate this issue further.

Our investigation commenced with 1*H*-indole (**1a**) and triethyl phosphite (**2a**) as starting materials with CH_3CN as the solvent. As shown in Table 1, by employing a two-electrode system with a carbon rod as an anode, a platinum plate as a cathode, and KI as the electrolyte, the desired N1 phosphoindole **3a** was produced in 92% yield with a 5 mA constant current in an undivided cell (Table 1, entry 1). The use of ^{n}Bu$_4$NI resulted in a reactivity that was similar to KI (entry 2) while KBr was less effective than KI (entry 3). As was expected, the desired high regioselective C2 phosphoindole **4a** could be obtained by using ^{n}Bu$_4$NClO$_4$ instead of KI (entry 4). Regarding the choice of supporting electrolyte, both ^{n}Bu$_4$NBF$_4$ and $NaBF_4$ were less effective than ^{n}Bu$_4$NClO$_4$ (entry 5 and 6). No desired product was obtained without electric current (entry 7). We also examined the reaction under various other conditions, including different electrolytes, solvent, and the amount of triethyl phosphite (**2a**). In the case of some conditions that resulted in low yields, the C3 phosphorylation product was also observed (see SI for full details regarding the optimization of the reaction conditions).

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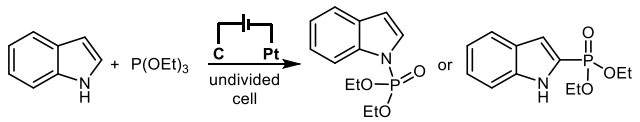
Table 1. Impact of reaction parameters on the direct oxidative cross-coupling.

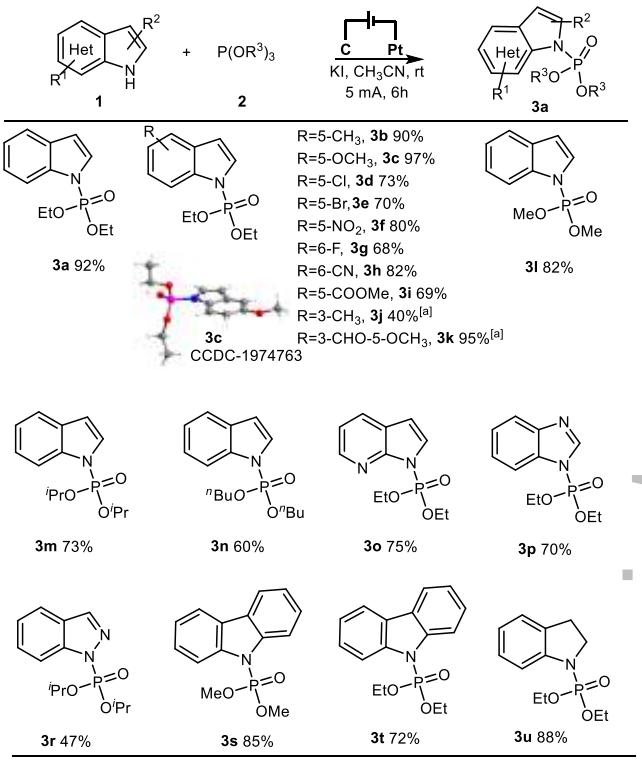


1a 2a 3a 4a

Entry[a]	electrolyte	P(OEt)$_3$	Yield [%][b] (3a or 4a)	
1	**KI**	**3.0 equiv.**	**92**	**n.d.**
2	^{n}Bu$_4$NI	3.0 equiv.	75	n.d.
3	KBr	3.0 equiv.	10	n.d.
4	**^{n}Bu$_4$NClO$_4$**	**4.0 equiv.**	**n.d.**	**75**
5	^{n}Bu$_4$NBF$_4$	4.0 equiv.	n.d.	30
6	NaBF$_4$	4.0 equiv.	n.d.	58
7 [c]	KI	3.0 equiv.	n.d.	n.d.

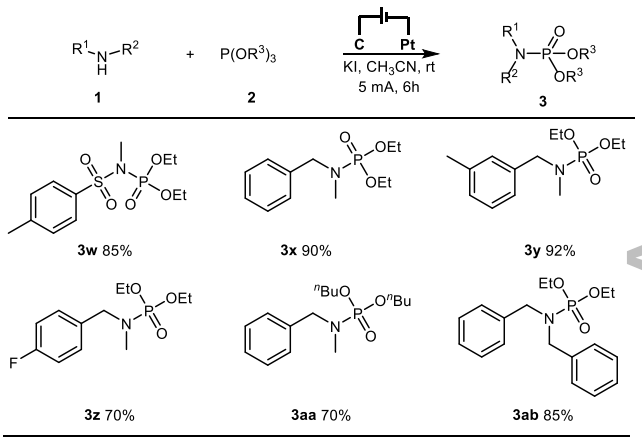
[a] Reaction conditions (**3a**): undivided cell, carbon rod anode, Pt cathode, **1a** (0.3 mmol), **2a** (0.9 mmol), KI (0.2 mmol), MeCN (5 mL), air, rt, 5 mA, 6 h. Reaction conditions (**4a**): Undivided cell, carbon rod anode, Pt cathode, **1a** (0.3 mmol), **2a** (1.2 mmol), ^{n}Bu$_4$NClO$_4$ (0.1 mmol), MeCN (10 mL), air, rt, 5 mA, 4 h. [b] Isolated yields. n.d. = not detected. [c] without electric current.

With the optimized conditions in hand, various substituted indoles and N-containing heterocycles **1** were reacted with trialkyl phosphite (Scheme 2). To our delight, the reaction could be readily extended to a variety of substituted indoles, and even methyl, methoxy, nitryl, halogen, cyano or carboxyl substituted indoles provided N1 phosphorylation products in moderate to good yields (Scheme 2, **3a**-**3k**). The structure of the product **3c** was also unequivocally established by an X-ray single-crystal analysis.[11] Additionally, despite the bulky steric hindrance or the presence of a long alkyl chain, P(O^{i}Pr)$_3$ and P(O^{n}Bu)$_3$ could both be used in the reaction, with the N1 phosphorylation products being produced in good yields (Scheme 2, **3l**-**3n**). It should also be noted that other N-containing heterocycles, such as 1*H*-pyrrolo[2,3-*b*]pyridine, 1*H*-benzo[*d*]imidazole, 1*H*-indazole, 9*H*-carbazole, and indoline were also found to be suitable reaction partners in this reaction (Scheme 2, **3p**-**3u**). However, no product was detected when diphenylphosphine oxide was used as a substrate.



Scheme 2. Substrate scope for the electrochemical oxidative N1 phosphorylation of indoles. Reaction conditions: undivided cell, carbon rod anode, Pt cathode, 1 (0.3 mmol), **2** (0.9 mmol), KI (0.2 mmol), MeCN (5 mL), air, rt, 5 mA, 6 h. Yield of isolated products. [a] KI (0.3 mmol), 10mA, 8h.

It is noteworthy that various alkylamines, such as *N*,4-dimethylbenzenesulfonamide, *N*-methyl-1-phenylmethanamine, and dibenzylamine could also be employed to easily give the desired products (Scheme 3, **3w**-**3ab**). The reaction was not successful for primary amines, e.g. phenylamine and butylamine. In a gram-scale reaction using the established electrochemical strategy, the reaction proceeded smoothly with **3a** being obtained in 84% yield (for more details, see the SI).



Scheme 3. Substrate scope for the electrochemical oxidative N-H phosphorylation. Reaction conditions: undivided cell, carbon rod anode, Pt cathode, **1** (0.3 mmol), **2a** (0.9 mmol), KI (0.3 mmol), MeCN (5 mL), air, rt, 5 mA, 6 h. Yield of isolated products.

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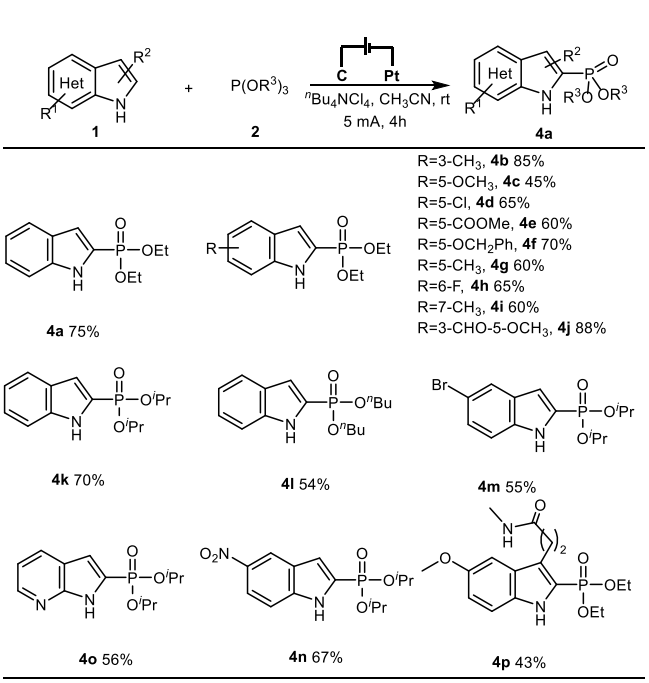
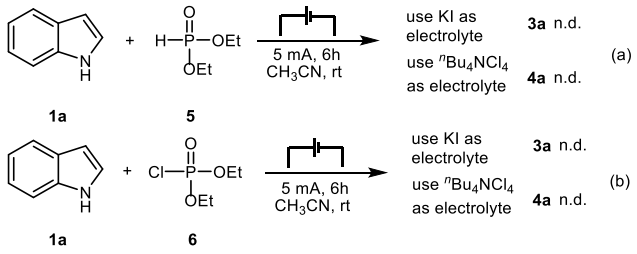


Scheme 4. Substrate scope for the electrochemical oxidative C2 phosphorylation of indoles. Reaction conditions: undivided cell, carbon rod anode, Pt cathode, **1** (0.3 mmol), **2** (1.2 mmol), $^{n}Bu_4NClO_4$ (0.1 mmol), MeCN (10 mL), air, rt, 5 mA, 4 h. Yield of isolated products.

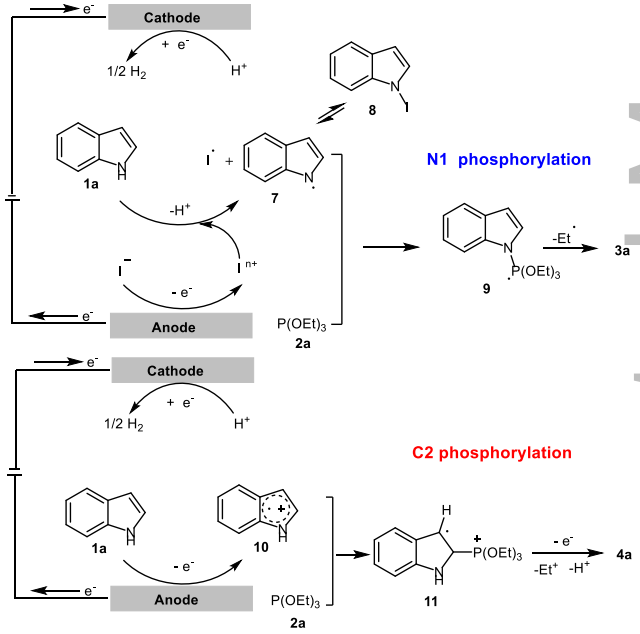
To gain preliminary mechanistic information concerning this transformation, some mechanistic experiments were performed. No product was detected when $HPO(OEt)_2$ was used as a substrate (Scheme 5a), which indicates that $HPO(OEt)_2$ is not the reaction intermediate. In addition, when the diethyl phosphorochloridate **6** was used as the substrate instead of **2a** to react with **1a** under the standard conditions, the corresponding product was not produced (Scheme 5b). This indicates that the diethyl phosphosphinyl iodide might not be the active species in this transformation.

Scheme 6 shows our proposed mechanism for this electrochemical transformation, based on the above results and previous studies.[12] For the N1 phosphorylation, 1*H*-indole **1a** reacts with the in-situ generated hypervalent iodine species to give intermediate **8**. The reversible homolytic cleavage of the N-iodo intermediate **8** gives an iodine radical and the nitrogen-centered radical **7** which was detected in the above EPR spectra. The nitrogen-centered radical **7** is then captured by **2a** to afford the intermediate **9**; finally, the ensuing dealkylation of **9** forms the N1 phosphorylation product **3a**. At the same time, protons were reduced at the cathode with the formation of H_2. With respect to C2 phosphorylation, **1a** is first oxidized at the anode to form the radical cation intermediate **10**, which then is captured by $P(OEt)_3$ **2a** and delivers the adduct **11**, and **11** then undergoes further anodic oxidation, dehydrogenation and ensuing dealkylation resulting in the formation of the C2 phosphorylation product **4a**.



Scheme 5. Mechanistic experiments

In summary, we reported on the regiodivergent N-H/C-H functionalization of free indoles via the use of different electrolytes; in addition, N-P coupling was also found to be compatible with various alkylamines. Under exogenous-oxidant-free and metal-catalyst-free electrochemical oxidation conditions, a diverse collection of valuable N1 and C2 phosphorylation products were obtained in moderate to high yields, by electrochemical anodic oxidation using different electrolytes to generate different active indole species. From the synthetic point of view, this protocol represents a green and simple strategy to produce phosphorus-containing indole derivatives from basic starting materials.



Scheme 6. Proposed mechanism.

Experimental Section

General Procedures for Preparation of the Phosphorylation Products 3a and 4a: For 3a: In an oven-dried three-necked flask (25 mL) equipped with a stirring bar, the indole **1a** (35.1 mg, 0.3 mmol), $P(OEt)_3$ (155.1 uL, 0.9 mmol), KI (33.2 mg, 0.2 mmol) were combined and added. Under the atmosphere of air, CH_3CN (5 mL) was injected respectively into the tubes via syringes. The flask was equipped with carbon rod (ϕ 6 mm, about 10 mm immersion depth in solution) as the anode and a platinum plate (15 mm×15 mm×0.3 mm) as the cathode. The reaction

mixture was stirred and electrolyzed at a constant current of 5 mA at room temperature for 6 h. After completion of the reaction, as indicated by TLC and GC-MS, the pure product (yield: 92%, 69.82 mg) was obtained by flash column chromatography on silica gel (eluent: petroleum ether/ethyl acetate= 10:1). **For 4a:** Indole **1a** (35.1 mg, 0.3 mmol), $P(OEt)_3$ (206.8 uL, 1.2 mmol), $^nBu_4NClO_4$ (34.2 mg, 0.1 mmol) were combined and added. Under the atmosphere of air, CH_3CN (10 mL) was injected respectively into the tubes via syringes. The flask was equipped with graphite rod (ϕ 6 mm, about 10 mm immersion depth in solution) as the anode and platinum plate (15 mm×15 mm×0.3 mm) as the cathode. The reaction mixture was stirred and electrolyzed at a constant current of 5 mA at room temperature for 4 h. After completion of the reaction, as indicated by TLC and GC-MS, the pure product (yield: 75%, 56.93 mg) was obtained by flash column chromatography on silica gel (eluent: petroleum ether/ethyl acetate= 5:1). The spectroscopic data of the products **3a** and **4a** are presented below. All of the known compounds gave satisfactory spectroscopic values and are analogue to spectroscopic data reported in the literature. All the known compounds had satisfactory spectroscopic features which were analogous to spectroscopic data reported in the literature. **3a:** ^{1}H NMR (400 MHz, Chloroform-d) δ 7.75 (d, *J* = 8.2 Hz, 1H), 7.59 (d, *J* = 7.8 Hz, 1H), 7.44 (dd, *J* = 3.2, 1.6 Hz, 1H), 7.29-7.24 (m, 1H), 7.23-7.16 (m, 1H), 6.63 (q, *J* = 3.1 Hz, 1H), 4.23-4.13 (m, 2H), 4.06-3.95 (m, 2H), 1.27-1.23 (m, 6H). ^{13}C NMR (101 MHz, Chloroform-d) δ 136.61 (d, *J* = 4.8 Hz), 130.82 (d, *J* = 10.2 Hz), 128.47 (d, *J* = 7.0 Hz), 123.28, 121.91, 120.78, 113.29, 107.08 (d, *J* = 8.5 Hz), 63.65 (d, *J* = 4.9 Hz), 15.69 (d, *J* = 6.8 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ−3.07. HRMS (ESI) cald. for $(M+H)^+C_{12}H_{17}NO_3P$: 254.0941; found, 254.0943. **4a:** ^{1}H NMR (400 MHz, Chloroform-d) δ 10.53 (s, 1H), 7.68 (d, J = 8.0 Hz, 1H), 7.53 (d, *J* = 8.3 Hz, 1H), 7.29 (t, *J* = 7.6 Hz, 1H), 7.14 (t, *J* = 7.5 Hz, 1H), 7.05 (dd, *J* = 4.1, 1.6 Hz, 1H), 4.22-4.11 (m, 4H), 1.34 (t, *J* = 7.1 Hz, 6H). 13C NMR (101 MHz, Chloroform-d) δ 138.42 (d, *J* = 12.9 Hz), 127.34 (d, *J* = 15.5 Hz), 123.53 (d, *J* = 220.18 Hz), 124.33, 121.64, 120.36, 112.30, 111.49 (d, *J* = 17.0 Hz), 62.79 (d, *J* = 5.0 Hz), 16.19 (d, *J* = 6.7 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 10.95. HRMS (ESI) calcd. for $(M+H)^+C_{12}H_{16}NO_3P$: 254.0941; found 254.0947.

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References

[1] a) D. A. Horton, G. T. Bourne, M. L. Smythe, *Chem. Rev*. **2003**, *103*, 893-930; b) F.-E. Chen, J. Huang, *Chem. Rev*. **2005**, *105*, 4671-4706; c) C. Zheng, S.-L. You, *Nat. Prod. Rep*. **2019**, *36*, 1589-1605.

[2] a) M.-Z. Zhang, Q. Chen, G.-F. Yang, *Eur. J. Med. Chem*. **2015**, *89*, 421-441; b) M. Sechi, M. Derudas, R. Dallocchio, A. Dessì, A. Bacchi, L. Sannia, F. Carta, M. Palomba, O. Ragab, C. Chan, R. Shoemaker, S. Sei, R. Dayam, N. Neamati, *J. Med. Chem*. **2004**, *47*, 5298-5310.

[3] a) Z. Ding, S.-C. Huang, R. B. Kaner, *J. Mater. Chem*. **2009**, *19*, 2588-2592; b) D. F. Taber, P. K. Tirunahari, *Tetrahedron* **2011**, *67*, 7195-7210; c) T.-S. Mei, L. Kou, S. Ma, K. M. Engle, J.-Q. Yu, *Synthesis* **2012**, *44*, 1778-1791.

[4] For selected reviews, see: a) M. Bandini, A. Eichholzer, *Angew. Chem. Int. Ed.* 2009, *48*, 9608-9644; b) S. Liu, F. Zhao, X. Chen, G.-J. Deng, H. Huang, *Adv. Synth. Catal.* **2020**, *362*, 3795-3823; c) A. H. Sandtorv, *Adv. Synth. Catal.*, **2015**, *357*, 2403-2435; d) L. Joucla, L. Djakovitch, *Adv. Synth. Catal*. **2009**, *351*, 673-714; e) Y. Yang, Z. Shi, *Chem. Commun*. **2018**, *54*, 1676-1685; f) S. H. Cho, J. Y. Kim, J. Kwak, S. Chang, *Chem. Soc. Rev*. **2011**, *40*, 5068-5083; g) G. Bartoli, G. Bencivenni, R. Dalpozzo, *Chem. Soc. Rev.* **2010**, *39*, 4449-4465; (h) J. Wencel-Delord, F. Glorius, *Nat. Chem*. **2013**, *5*, 369-375; (i) Y. Yang, J. Lan, J. You, *Chem. Rev.* **2017**, *117*, 8787-8863; (j) P. Gandeepan, L. Ackermann, *Chem. Rev*. **2019**, *119*, 2192-2452; (k) C.-L. Sun, Z.-J. Shi, *Chem. Rev.* **2014**, *114*, 9219-9280; (l) C. S. Yeung, V. M. Dong, *Chem. Rev*. **2011**, *111*, 1215-1292.

[5] a) C. Nájera, I. P. Beletskaya, M. Yus, *Chem. Soc. Rev*. **2019**, 48, 4515-4618; b) J. A. Leitch, Y. Bhonoah, C. G. Frost, *ACS Catal*. **2017**, 7, 5618-5627; c) L. Ping, D. S. Chung, J. Bouffard, S.-g. Lee, *Chem. Soc. Rev*. **2017**, 46, 4299-4328; d) Q. Zhong, S. Qin, Jia. Hu, H. Zhang, *Angew. Chem. Int. Ed.* **2018**, 57, 14891-14895.

[6] a) Y. Zhao, J. Zhao, *Adv. Synth. Catal*. **2020**, 362, 1309-1316; b) N. P. Grimster, C. Gauntlett, C. R. A. Godfrey, M. J. Gaunt, *Angew. Chem. Int. Ed*. **2005**, 44, 3125-3129; c) D. R. Stuart, E. Villemure, K. Fagnou, *J. Am. Chem. Soc*. 2007, 129, 12072-12073; d) R. J. Phipps, N. P. Grimster, M. J. Gaunt, *J. Am. Chem. Soc*. **2008**, 130, 8172-8174; e) B. S. Lane, M. A. Brown, D. Sames, *J. Am. Chem. Soc*. **2005**, *127*, 8050-8057; f) S. Kirchberg, R. Fröhlich, A. Studer, *Angew. Chem. Int. Ed*. **2009**, *48*, 4235-4238.

[7] For selected reviews, see: a) N. Sauermann, T. H. Meyer, Y. Qiu, L. Ackermann, *ACS Catal*. **2018**, *8*, 7086-7103; b) M. D. Kärkäs, *Chem. Soc. Rev.* **2018**, *47*, 5786-5865; c) Y. Zhao, W. Xia, *Chem. Soc. Rev*. **2018**, 47, 2591 2608; d) C. Ma, P. Fang, T.-S. Mei, *ACS Catal.* **2018**, *8*, 7179-7189; e) S. Tang, Y. Liu, A. Lei, *Chem*, **2018**, *4*, 27-45; f) A. Jutand, *Chem. Rev.* 2008, *108*, 2300-2347. g) J. C. Siu, N. Fu, S. Lin, *Acc. Chem. Res*. **2020**, *53*, 547-560. h) P. Xiong, H.-C. Xu, *Acc. Chem. Res*. **2019**, *52*, 3339-3350. i) Y. Yu, J.-S. Zhong, K. Xu, Y.-F. Yuan, K.-Y. Ye, *Adv. Synth. Catal*. **2020**, 362, 2102-2119. j) P. Gandeepan, L. Finger, T. Meyer, L. Ackermann, *Chem. Soc. Rev*. **2020**, *49*, 4254-4272.

[8] a) X. Dong, R. Wang, W. Jin, C. Liu, *Org. Lett.* **2020**, *22*, 3062-3066; b) K. Liu, A. Lei, *Nat. Commun*. **2017**, *8*, 775; c) L. Sun, Z. Li, H. Chen, H. Jiang, *Green Chem*. **2019**, *21*, 2732-2738; d) P. Wang, A. Lei, *Angew. Chem. Int. Ed*. **2017**, *56*, 3009-3013; e) K.-S. Du, J.-M. Huang, *Org. Lett.* **2018**, *20*, 2911-2915; f) Y. Jiang, K. Xu, C. Zeng, *Chem. Rev*. **2018**, *118*, 4485-4540; g) Y. Qiu, A. Scheremetjew, L. H. Finger, L. Ackermann, *Chem.-Eur. J.* **2020**, *26*, 3241-3246.

[9] a) S. Liang, C.-C. Zeng, X.-G. Luo, F.-z. Ren, H.-Y. Tian, B.-G. Sun, R. D. Little, *Green Chem*. **2016**, *18*, 2222-2230; b) B. Huang, C. Yang, J. Zhou, W. Xia, *Chem. Commun.* **2020**, *56*, 5010-5013.

[10] a) L. Chen, Y.-X. Zou, *Org. Biomol. Chem*. **2018**, *16*, 7544-7556; b) W. Tang, X. Zhang, *Chem. Rev*. **2003**, *103*, 3029-3070; (c) L. Bialy, H. Waldmann, *Angew. Chem. Int. Ed*. **2005**, *44*, 3814-3839; d) K. Moonen, I. Laureyn, C. V. Stevens, *Chem. Rev*. **2004**, *104*, 6177-6216.

[11] CCDC-1974763 contains the supplementary crystallographic data for **3c**. These data can be obtained free

10.1002/adsc.202000997

of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

[12] a) Y. Wang, Z. Zha, Z. Wang, *Green Chem*. **2017**, *19*, 4769-4773; b) C.-C. Sun, K. Xu, C.-C. Zeng, B.-G. Sun, *Adv. Synth. Catal.* **2019**, *361*, 4041-4047; c) Y. Yuan, J. Qiao, A. Lei, *Chem. Commun.* **2019**, *55*, 4230-4233; d) S. Guo, Z. Fu, H. Cai, *Eur. J. Org. Chem*. **2019**, *2019*, 1808-1814. e) X.-Y. Yu, Q.-Q. Zhao, J. Chen, W.-J. Xiao, J.-R. Chen, *Acc. Chem. Res*. **2020**, *53*, 1066-1083.

10.1002/adsc.202000997

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