

Pd-Catalyzed Assembly of Fluoren-9-ones by Merging of C–H Activation and Difluorocarbene Transfer

Xiaobing Liu, Heyun Sheng, Yao Zhou, and Qiuling Song*



Cite This: *Org. Lett.* 2021, 23, 2543–2547



Read Online

ACCESS |



Metrics & More

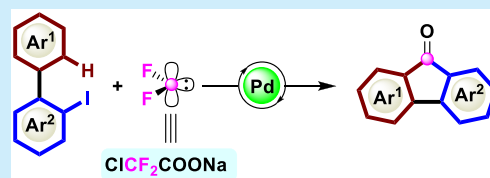


Article Recommendations



Supporting Information

ABSTRACT: We disclose a novel Pd-catalyzed assembly of fluoren-9-ones by merging of C–H activation and difluorocarbene transfer. $\text{ClCF}_2\text{COONa}$ served as a difluorocarbene precursor to be harnessed as a carbonyl source in this transformation. The current protocol enables us to afford fluoren-9-ones in high yields with excellent functional group compatibility, which also represents the first example of using difluorocarbene as a coupling partner in transition-metal-catalyzed C–H activation.

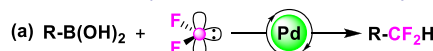


Sodium chlorodifluoroacetate ($\text{ClCF}_2\text{COONa}$) has loomed as a promising reagent in organic synthesis, which can be incubated into difluorocarbene via C–Cl and C–C bond cleavage.¹ There are three cases for further utilization of the in situ generated difluorocarbene: (1) as the difluoromethyl reagent; (2) as the C1 synthon; and (3) as the carbonyl source. With respect to previous applications of sodium chlorodifluoroacetate, nucleophiles or amine derivatives are a prerequisite for the triumphant transformations of $\text{ClCF}_2\text{COONa}$. To our knowledge, the utilization of electrophiles or nonamine derivatives to react with $\text{ClCF}_2\text{COONa}$ is still far from being supplemented. Especially, the treatment of $\text{ClCF}_2\text{COONa}$ as an efficient coupling partner in transition-metal-catalyzed C–H activation has never been documented heretofore.

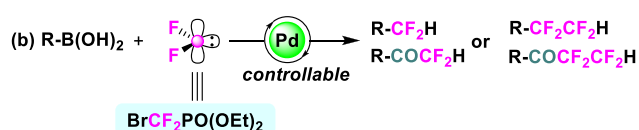
During the past years, a vast array of strategies have been developed for difluorocarbene transfer reactions. In sharp contrast to the nonfluorinated carbene complex, the catalytic formation of the metal= CF_2 complex and the application of carbon nucleophiles to transfer the difluorocarbene still remain as long-standing challenges in organic chemistry.² In this regard, Zhang's group disclosed an unprecedented Pd-catalyzed difluoromethylation of aryl boronic acids with bromodifluoroacetate (Scheme 1a), in which $(\text{L}_n)\text{Pd}=\text{CF}_2$ was formed as the crucial intermediate.³ Soon afterward, Xiao and co-workers also demonstrated an outstanding Pd-catalyzed transfer of difluorocarbene using $\text{Ph}_3\text{P}^+\text{CF}_2\text{CO}_2^-$ (PDFA) as the difluorocarbene source (Scheme 1a).⁴ In 2017, Zhang's group once again successfully developed a Pd-catalyzed ClCF_2H -triggered formation of difluoromethylated arenes (Scheme 1a).⁵ Recently, the same group described a preeminent difluorocarbene transfer reaction by using diethyl bromodifluoromethylphosphonate as a difluorocarbene precursor, in which four types of fluoroalkylated arenes were achieved in a controllable catalytic way (Scheme 1b).⁶ Due to our persistent interest in the transformations of halogenated difluoro compounds,⁷ herein we report an effective method-

Scheme 1. Pd-Catalyzed Transfer of Difluorocarbene

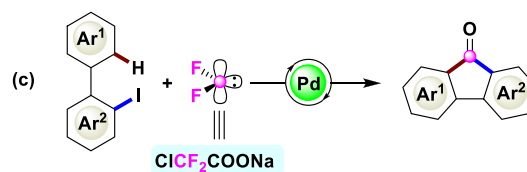
Previous work (Transfer of difluorocarbene)



$\text{BrCF}_2\text{COOEt}$, $\text{Ph}_3\text{P}^+\text{CF}_2\text{COO}^-$ or ClCF_2H



This work (Merging of C–H activation and difluorocarbene transfer)



ology by merging of C–H activation and difluorocarbene transfer to access fluoren-9-ones⁸ (Scheme 1c). In this process, difluorocarbene acts as a carbonyl source and simultaneously forms two $\text{C}(\text{sp}^2)\text{--C}(\text{sp}^2)$ bonds, which also represents the first example using difluorocarbene as a coupling partner in transition-metal-catalyzed C–H activation.

We selected 2-iodobiphenyl (1a) and sodium chlorodifluoroacetate (2) as benchmark substrates to initiate our

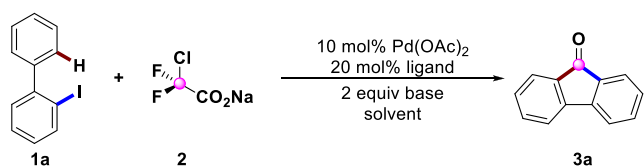
Received: February 8, 2021

Published: March 22, 2021



research. Despondingly, when the reaction was conducted in the presence of Pd(OAc)₂ by using Na₂CO₃ as base, a stagnant reaction was observed (Table 1, entry 1). To our delight, 9H-

Table 1. Optimization of the Reaction Conditions



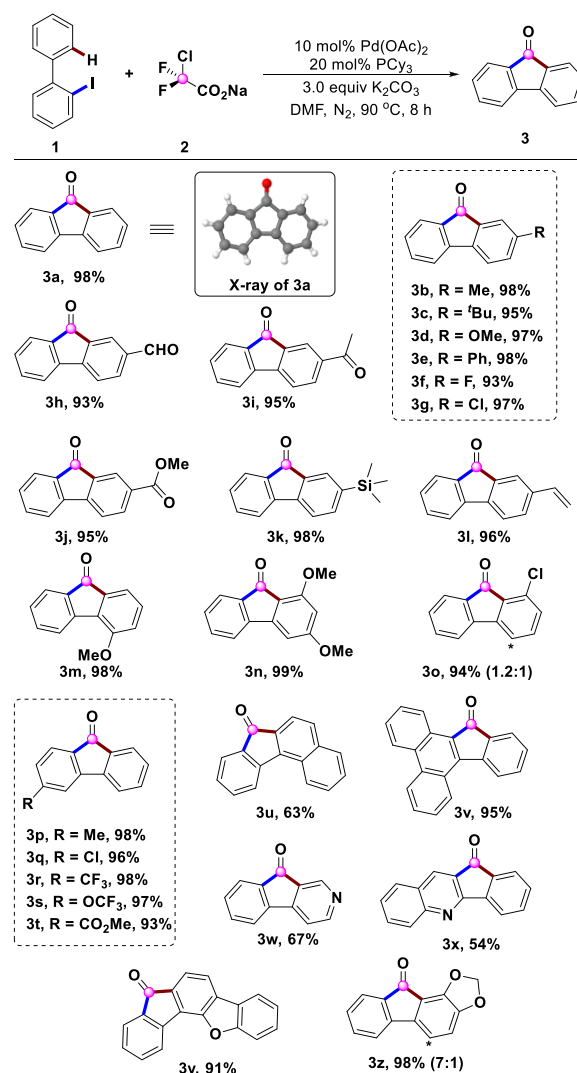
entry ^a	ligand	base	solvent	yield ^b
1	--	Na ₂ CO ₃	DMF	trace
2	PPh ₃	Na ₂ CO ₃	DMF	13%
3	<i>p</i> -OMe(C ₆ H ₄) ₃ P	Na ₂ CO ₃	DMF	34%
4	<i>p</i> -F(C ₆ H ₄) ₃ P	Na ₂ CO ₃	DMF	10%
5	dppe	Na ₂ CO ₃	DMF	trace
6	PCy ₃	Na ₂ CO ₃	DMF	73%
7	PCy ₃	K ₂ CO ₃	DMF	87%
8	PCy ₃	K ₃ PO ₄	DMF	69%
9	PCy ₃	NaOAc	DMF	trace
10	PCy ₃	Et ₃ N	DMF	n.r.
11 ^c	PCy ₃	K ₂ CO ₃	DMF	98%
12	PCy ₃	K ₂ CO ₃	CH ₃ CN	81%
13	PCy ₃	K ₂ CO ₃	1,4-dioxane	<10%
14	PCy ₃	K ₂ CO ₃	CHCl ₃	trace
15	PCy ₃	K ₂ CO ₃	toluene	n.r.
16 ^d	PCy ₃	K ₂ CO ₃	DMF	87%
17 ^e	PCy ₃	K ₂ CO ₃	DMF	38%
18 ^f	PCy ₃	K ₂ CO ₃	DMF	n.r.

^aReaction conditions: 0.2 mmol of 1a, 0.4 mmol of 2, 10 mol % of Pd(OAc)₂, 20 mol % of ligand, 2 equiv of base, 2 mL of solvent, at N₂ for 8 h under 90 °C. ^bIsolated yield. ^c3.0 equiv of K₂CO₃. ^d5 mol % of Pd(OAc)₂ + 10 mol % of PCy₃. ^eAir atmosphere. ^fWithout Pd(OAc)₂.

fluoren-9-one 3a was achieved in 13% yield when triphenylphosphine served as the additive. Since the ligand could significantly enhance the reaction efficiency, we then investigated a suite of different phosphine ligands (Table 1, entries 2–6). Among the ligands inspected, tricyclohexylphosphine displayed the best catalytic partner, in which the desired 3a could be isolated in 73% yield (Table 1, entry 6). Subsequently, a battery of bases were examined (Table 1, entries 7–10). K₃PO₄, NaOAc, and Et₃N were proved to be inefficient or even ineffective. On the contrary, K₂CO₃ turned out to be the optimum accelerant to deliver the 9H-fluoren-9-one 3a in 87% yield (Table 1, entry 7). The augment of the amount of K₂CO₃ was beneficial to this difluorocarbene transfer reaction, and the yield of 3a could be increased to 98% (Table 1, entry 11). As a follow-up optimization, we also screened a range of solvents, and the results showed that DMF was still the optimal reaction medium (Table 1, entries 12–15). When the loading of catalyst was reduced, an inferior yield of 3a was obtained (Table 1, entry 16). When the model reaction was conducted under air atmosphere, the yield of 9H-fluoren-9-one 3a was sharply decreased to 37% (Table 1, entry 17). The control experiment indicated that Pd(OAc)₂ was indispensable for this transformation (Table 1, entry 18).

With the optimized reaction conditions in hand, the substrate scope of this novel Pd-catalyzed assembly of fluoren-9-ones was then investigated (Scheme 2). The electronic effect of the substituents installed on 2-iodinebi-

Scheme 2. Substrate Scope with Respect to 2-Iodobiphenyls^a



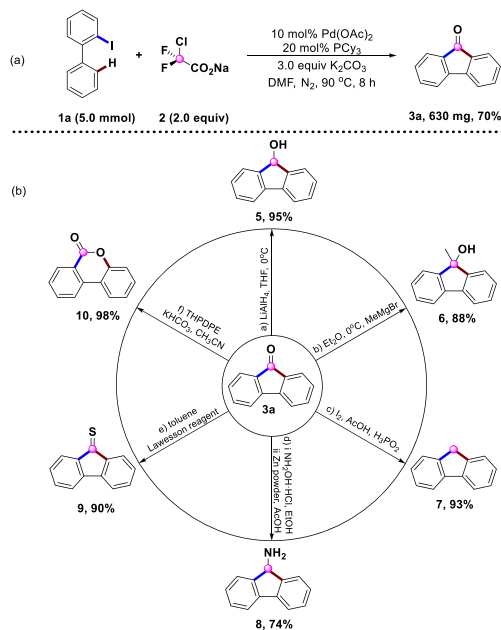
^aAll reactions unless otherwise stated were carried out with 1 (0.2 mmol), 2 (0.4 mmol), Pd(OAc)₂ (10 mol %), PCy₃ (20 mol %), and K₂CO₃ (3.0 equiv) in DMF (2 mL) under N₂ at 90 °C for 8 h.

phenyls had no evident distinctions. Regardless of the 2-iodinebiphenyls bearing the electron-withdrawing or electron-donating groups on the aromatic ring, the 2-iodinebiphenyls can almost be converted equivalently, enabling the formation of the corresponding substituted fluorenones in excellent yields (3a–3t). The structure of 3a was definitely confirmed by X-ray single-crystal diffraction. It should be noted that a succession of sensitive functional groups, such as chlorine, formyl, ketone, ester, TMS, and vinyl, were well amenable to this Pd-catalyzed C–H activation, which makes the further structural elaboration of the fluoren-9-ones readily available. In addition to *para*-substituted 2-iodinebiphenyls, *meta*- and *ortho*-substituted 2-iodinebiphenyls were also compatible in this Pd-catalyzed difluorocarbene transfer reaction. The targeted products (3m–3o) were obtained in 93%–99% yields. A range of 2-iodinebiphenyls with different substituents installed on the ring of iodobenzene were also certified to be good candidates to assemble the fluorenones (3p–3t) in 93%–98% yields. Gladly, the subsection of fused 2-iodinebiaryls to this

transformation was also successful, and the expected products **3u** and **3v** could be isolated in 63% and 95% yields, respectively. Aside from fused rings, heteroaromatic 2-iodobiphenyls (**2u–2z**) could be smoothly engaged in this Pd-catalyzed C–H activation as well, rendering the desired fluorenones **3u–3z** in moderate to excellent yields.

In order to showcase the practicability of this Pd-catalyzed assembly of fluorenones, we executed the large-scale synthesis and further synthetic manipulations. When the reaction was scaled up to 5 mmol, the targeted **3a** was achieved in 70% yield without loss of the efficiency (Scheme 3a). As a versatile

Scheme 3. Larger Synthesis and Synthetic Applications

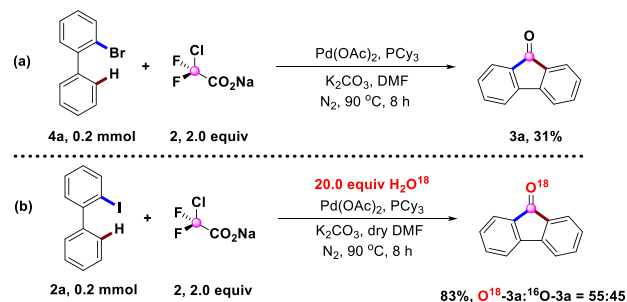


synthon, fluorenones can be transformed into a variety of functionalized organic molecules (Scheme 3b). Fluoren-9-one **3a** could be easily converted into 9*H*-fluoren-9-ol **5** and 9-methyl-9*H*-fluoren-9-ol **6** in 95% and 88% yields, respectively.^{9,10} In addition, **3a** could also be reduced into 9*H*-fluorene **7** in high yield using the hypophosphorous acid–iodine reducing system.¹¹ According to the reported literature, 9*H*-fluoren-9-amine **8**, 9*H*-fluorene-9-thione **9**, and 6*H*-benzo[*c*]chromen-6-one **10** could be readily acquired from **3a** in one or two steps as well.^{12–14}

In order to gain further insight into the mechanism for this Pd-catalyzed C–H activation by merging of difluorocarbene transfer, we conducted the control experiments and labeling experiments. When 2-iodo-1,1'-biphenyl **2a** was replaced by 2-bromo-1,1'-biphenyl **4a**, the yield of **3a** was sharply decreased to 31%, indicating that the reactivity of iodobenzenes is much higher than that of bromobenzenes in this transformation (Scheme 4a). To notarize the origination of the carbonyl oxygen atom of the targeted 9*H*-fluoren-9-one, an isotope labeling experiment was executed. When 20 equiv of H₂¹⁸O was added to the reaction, 55% of ¹⁸O-labeled product **3a** was detected by GC-MS (Scheme 4b). This result showed that the oxygen atom in the desired product should originate from the water in the reaction system, which facilitated the hydrolysis of difluorocarbene.

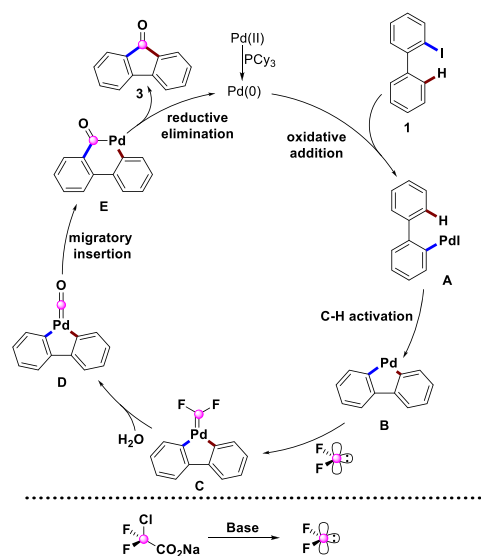
Based on the existing literature and our previous work,^{1,7,8,15} we proposed a possible mechanism for this Pd-catalyzed

Scheme 4. Control Experiment and Labeling Experiment



construction of fluorenones. As showcased in Scheme 5, first, oxidative addition of **1** gives rise to the formation of aryl

Scheme 5. Primary Mechanism Studies



palladium species **A**, which subsequently undergoes C–H bond activation to render the intermediate **B**. With the assistance of base, difluorocarbene is generated from the sodium difluorochloroacetate in situ, which is then captured by metal palladium to deliver the intermediate **C**. The hydrolysis of intermediate **C** produces the palladium complex **D**. The active species **D** goes through the migration insertion to provide the six-membered palladacycle **E**. Finally, intermediate **E** suffers from reductive elimination to furnish the desired product **3**.

In summary, we have successfully established an efficacious Pd-catalyzed difluorocarbene transfer for the construction of fluoren-9-ones. In the current process, difluorocarbene acts as a carbonyl source and simultaneously forms two C(sp²)–C(sp²) bonds, which also represents the first example using difluorocarbene as a coupling reagent in C–H activation. A vast array of functionalized fluoren-9-ones were achieved in high yields via C–H activation with wide substrate scope. This methodology is readily scaled up for the construction of fluoren-9-ones without loss of efficiency. Further applications of this synthetic strategy by merging of C–H activation and difluorocarbene transfer are underway in our group.

■ ASSOCIATED CONTENT**SI Supporting Information**

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.orglett.1c00467>.

General experimental procedures, crystallographic data, and spectroscopic data for the corresponding products (PDF)

Accession Codes

CCDC 2049630 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

■ AUTHOR INFORMATION**Corresponding Author**

Qiuling Song – Institute of Next Generation Matter

Transformation, College of Materials Science & Engineering and College of Chemical Engineering at Huaqiao University, Xiamen 361021, Fujian, P. R. China; Fujian University Key Laboratory of Molecule Synthesis and Function Discovery, College of Chemistry, Fuzhou University, Fuzhou 350108, Fujian, P. R. China; State Key Laboratory of Organometallic Chemistry and Key Laboratory of Organofluorine Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences, Shanghai 200032, P. R. China; orcid.org/0000-0002-9836-8860; Email: qsong@hqu.edu.cn

Authors

Xiaobing Liu – Institute of Next Generation Matter

Transformation, College of Materials Science & Engineering and College of Chemical Engineering at Huaqiao University, Xiamen 361021, Fujian, P. R. China

Heyun Sheng – Institute of Next Generation Matter

Transformation, College of Materials Science & Engineering and College of Chemical Engineering at Huaqiao University, Xiamen 361021, Fujian, P. R. China

Yao Zhou – College of Chemistry and Chemical Engineering, Hubei Normal University, Huangshi 435002, Hubei, P. R. China

Complete contact information is available at:

<https://pubs.acs.org/doi/10.1021/acs.orglett.1c00467>

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

Financial support from the National Natural Science Foundation (21772046) and the Natural Science Foundation of Fujian Province (2016J01064) is gratefully acknowledged. We also thank the Instrumental Analysis Center of Huaqiao University for analysis support.

■ REFERENCES

(1) (a) Mehta, V. P.; Greaney, M. F. S., N-, and Se-difluoromethylation using sodium chlorodifluoroacetate. *Org. Lett.* **2013**, *15*, 5036. (b) Yan, Y. Y.; Cui, C.; Wang, J. Y.; Li, S. Q.; Tang, L.; Liu, Y. Q. Transition metal-free C-F/C-Cl/C-C cleavage of ClCF₂COONa for the synthesis of heterocycles. *Org. Biomol. Chem.* **2019**, *17*, 8071. (c) Ma, X. X.; Deng, S. L.; Song, Q. L.

Halodifluoroacetates as formylation reagents with various amines via unprecedented quadruple cleavage. *Org. Chem. Front.* **2018**, *5*, 3505. (d) Zhang, P. S.; Chen, W. Z.; Liu, M. C.; Wu, H. Y. Synthesis of 3-HCF₂S-chromones through tandem oxa-michael addition and oxidative difluoromethylthiolation. *Org. Lett.* **2019**, *21*, 9326. (e) Wang, Y.; Zhou, Y.; Song, Q. L. [3 + 1+1] Type cyclization of ClCF₂COONa for the assembly of imidazoles and tetrazoles via in-situ generated isocyanides. *Chem. Commun.* **2020**, *56*, 6106. (f) Ando, M.; Wada, T.; Sato, N. Facile one-pot synthesis of N-difluoromethyl-2-pyridone derivatives. *Org. Lett.* **2006**, *8*, 3805. (g) Sperry, J. B.; Sutherland, K. A safe and practical procedure for the difluoromethylation of methyl 4-hydroxy-3-iodobenzoate. *Org. Process Res. Dev.* **2011**, *15*, 721. (h) Thomason, C. S.; Wang, L. H.; Dolbier, W. R. Use of fluoroform as a source of difluorocarbene in the synthesis of N-CF₂H heterocycles and difluoromethoxyppyridines. *J. Fluorine Chem.* **2014**, *168*, 34. (i) Petko, K. I. Difluoromethylation of parent azoles. *J. Fluorine Chem.* **2018**, *205*, 5. (j) Li, Z. Y.; Dong, J. N.; Yuan, Z. H.; Yang, D.-Y.; Weng, Z. Q. One-pot synthesis of 3-difluoromethyl benzoxazole-2-thiones. *Org. Lett.* **2018**, *20*, 6407.

(2) (a) Takahira, Y.; Morizawa, Y. Ruthenium-catalyzed olefin cross-metathesis with tetrafluoroethylene and analogous fluorolefins. *J. Am. Chem. Soc.* **2015**, *137*, 7031. (b) Fuchibe, K.; Aono, T.; Hu, J.; Ichikawa, J. J. Copper(I)-catalyzed [4 + 1] cycloaddition of silyl dienol ethers with sodium bromodifluoroacetate: access to β,β-difluorocyclopentanone derivatives. *Org. Lett.* **2016**, *18*, 4502.

(3) Feng, Z.; Min, Q.-Q.; Zhang, X. G. Access to difluoromethylated arenes by Pd-catalyzed reaction of arylboronic acids with bromodifluoroacetate. *Org. Lett.* **2016**, *18*, 44.

(4) Deng, X.-Y.; Lin, J.-H.; Xiao, J.-C. Pd-Catalyzed transfer of difluorocarbene. *Org. Lett.* **2016**, *18*, 4384.

(5) Feng, Z.; Min, Q.-Q.; Fu, X.-P.; An, L.; Zhang, X. G. Chlorodifluoromethane-triggered formation of difluoromethylated arenes catalyzed by palladium. *Nat. Chem.* **2017**, *9*, 918.

(6) Fu, X.-P.; Xue, X.-S.; Zhang, X.-Y.; Xiao, Y.-L.; Zhang, S.; Guo, Y.-L.; Leng, X. b.; Houk, K. N.; Zhang, X. G. Controllable catalytic difluorocarbene transfer enables access to diversified fluoroalkylated arenes. *Nat. Chem.* **2019**, *11*, 948.

(7) (a) Ma, X. X.; Yu, X. X.; Huang, H.; Zhou, Y.; Song, Q. L. Synthesis of thiazoles and isothiazoles via three-component reaction of enaminoesters, sulfur, and bromodifluoroacetamides/esters. *Org. Lett.* **2020**, *22*, 5284. (b) Ma, X. X.; Zhou, Y.; Song, Q. L. Synthesis of β-aminoenones via cross-coupling of in-situ generated isocyanides with 1,3-dicarbonyl compounds. *Org. Lett.* **2018**, *20*, 4777. (c) Jin, S. N.; Kuang, Z. J.; Song, Q. L. Precise construction of SCF₂H or SeCF₂H groups on heteroarenes generated in situ from CF₃-containing 1,3-enynes. *Org. Lett.* **2020**, *22*, 615. (d) Su, J. K.; Ma, X. X.; Ou, Z. L.; Song, Q. L. Deconstructive functionalizations of unstrained carbon-nitrogen cleavage enabled by difluorocarbene. *ACS Cent. Sci.* **2020**, *6*, 1819. (e) Yu, C. J.; Su, J. K.; Ma, X. X.; Zhou, Y.; Song, Q. L. Difluoromethylation of tosylhydrazone compounds with chlorodifluoromethane under mild conditions. *Asian J. Org. Chem.* **2019**, *8*, 694. (f) Kong, W. G.; An, H. J.; Song, Q. L. Visible-light-induced thiotrifluoromethylation of terminal alkenes with sodium triflate and benzenesulfonothioates. *Chem. Commun.* **2017**, *53*, 8968. (g) Ma, X. X.; Mai, S. Y.; Zhou, Y.; Cheng, G.-J.; Song, Q. L. Dual role of ethyl bromodifluoroacetate in the formation of fluorine-containing heteroaromatic compounds. *Chem. Commun.* **2018**, *54*, 8960. (h) Yu, X. X.; Zhou, Y.; Ma, X. X.; Song, Q. L. Transition metal-free assembly of 1,3,5-triazines by using ethyl bromodifluoroacetate as C1 source. *Chem. Commun.* **2019**, *55*, 8079. (i) Ma, X. X.; Huang, H.; Su, J. K.; Song, Z. Y.; Nakano, T.; Song, Q. L. Synthesis of CF₂H-containing oxime ethers derivatives from ClCF₂H, tert-butyl nitrile and indoles. *Chin. J. Chem.* **2020**, *38*, 63. (j) Ma, X. X.; Su, J. K.; Zhang, X. G.; Song, Q. L. Chlorodifluoromethane as a C1 synthon in the assembly of N-containing compounds. *iScience* **2019**, *19*, 1. (k) Ma, X. X.; Song, Q. L. Recent progress on selective deconstructive modes of halodifluoromethyl and trifluoromethyl-containing reagents. *Chem. Soc. Rev.* **2020**, *49*, 9197. (l) Yu, C. J.; Ma, X. X.; Song, Q. L. Palladium-catalyzed cyanation of aryl halides with in situ generated

CN– from ClCF_2H and NaNH_2 . *Org. Chem. Front.* **2020**, *7*, 2950. (m) M, X. X.; Xuan, Q. Q.; Song, Q. L. N-H and O-H difluoromethylation of N-Heterocycles. *Huaxue Xuebao.* **2018**, *76*, 972.

(8) (a) Kumar, D. R.; Satyanarayana, G. Domino oxidative [Pd]-catalysis: one-pot synthesis of fluorenones starting from simple benzylamines and iodo arenes. *Org. Lett.* **2015**, *17*, 5894. (b) Chen, X.-Y.; Ozturk, S.; Sorensen, E. J. Synthesis of fluorenones from benzaldehydes and aryl iodides: dual C–H functionalizations using a transient directing group. *Org. Lett.* **2017**, *19*, 1140. (c) Konishi, H.; Futamata, S.; Wang, X.; Manabe, K. Rapid Formation of Fluoren-9-ones via Palladium-catalyzed external carbon monoxide-free carbonylation. *Adv. Synth. Catal.* **2018**, *360*, 1805. (d) Thirunavukkarasu, V. S.; Parthasarathy, K.; Cheng, C.-H. Synthesis of fluorenones from aromatic aldoxime ethers and aryl halides by palladium-catalyzed dual C-H activation and Heck cyclization. *Angew. Chem., Int. Ed.* **2008**, *47*, 9462. (e) Zhao, Y.-B.; Mariampillai, B.; Candito, D. A.; Laleu, B.; Li, M.; Lautens, M. Exploiting the divergent reactivity of aryl–palladium intermediates for the rapid assembly of fluorene and phenanthrene derivatives. *Angew. Chem., Int. Ed.* **2009**, *48*, 1849. (f) Shi, Z. Z.; Glorius, F. Synthesis of fluorenones via quaternary ammonium salt-promoted intramolecular dehydrogenative arylation of aldehydes. *Chem. Sci.* **2013**, *4*, 829. (g) Sun, D.; Li, B.; Lan, J.; Huang, Q.; You, J. Chelation-assisted Pd-catalyzed ortho-selective oxidative C–H/C–H cross-coupling of aromatic carboxylic acids with arenes and intramolecular Friedel–Crafts acylation: one-pot formation of fluorenones. *Chem. Commun.* **2016**, *52*, 3635. (h) Zhao, J.; Yue, D. W.; Campo, M. A.; Larock, R. C. An aryl to imido palladium migration process involving intramolecular C-H activation. *J. Am. Chem. Soc.* **2007**, *129*, 5288. (i) Shen, H.; Xiao, X.; Haj, M. K.; Willoughby, P. H.; Hoye, T. R. BF_3 -promoted, carbene-like, C-H insertion reactions of benzyne. *J. Am. Chem. Soc.* **2018**, *140*, 15616. (j) Campo, M. A.; Larock, R. C. Synthesis of fluoren-9-ones by the palladium-catalyzed cyclocarbonylation of o-halobiaryls. *J. Org. Chem.* **2002**, *67*, 5616. (k) Hoye, T. R.; Baire, B.; Niu, D. W.; Willoughby, P. H.; Woods, B. P. The hexadehydro-Diels–Alder reaction. *Nature* **2012**, *490*, 208. (l) Campo, M. A.; Larock, R. C. Synthesis of fluoren-9-ones via palladium-catalyzed cyclocarbonylation of o-halobiaryls. *Org. Lett.* **2000**, *2*, 3675. (m) Wang, Y.-F.; Xu, W.-G.; Sun, B.; Yu, Q.-Q.; Li, T.-J.; Zhang, F.-L. Monodentate transient directing group assisted Pd-catalyzed direct dehydrogenative cross-coupling of benzaldehydes with arenes toward 9-fluorenones. *J. Org. Chem.* **2019**, *84*, 13104.

(9) George, S. R. D.; Elton, T. E.; Harper, J. B. Electronic effects on the substitution reactions of benzhydrols and fluorenyl alcohols. Determination of mechanism and effects of antiaromaticity. *Org. Biomol. Chem.* **2015**, *13*, 10745.

(10) Bowen, M. E.; Aavula, B. R.; Mash, E. A. Use of 9-methylfluorene as an indicator in the titration of common group IA and group IIA organometallic reagents. *J. Org. Chem.* **2002**, *67*, 9087.

(11) Hicks, L. D.; Han, J. K.; Fry, A. J. Hypophosphorous acid–iodine: a novel reducing system. Part 1: Reduction of diaryl ketones to diaryl methylene derivatives. *Tetrahedron Lett.* **2000**, *41*, 7817.

(12) Konstandaras, N.; Dunn, M. H.; Guerry, M. S.; Barnett, C. D.; Cole, M. L.; Harper, J. B. The impact of cation structure upon the acidity of triazolium salts in dimethyl sulfoxide. *Org. Biomol. Chem.* **2020**, *18*, 66.

(13) Zhu, T.; Wu, X. X.; Yang, X. Z.; Sharma, B. Y.; Li, N.; Huang, J. M.; Wang, W. W.; Xing, W.; Zhao, Z. W.; Huang, H. One-pot catalytic cleavage of $\text{C}=\text{S}$ double bonds by Pd catalysts at room temperature. *Inorg. Chem.* **2018**, *57*, 9266.

(14) Khosravi, K.; Naserifar, S. 1,1,2,2-Tetrahydroperoxy-1,2-diphenylethane: an efficient and high oxygen content oxidant in various oxidative reactions. *Tetrahedron* **2018**, *74*, 6584.

(15) (a) Gu, J. W.; Guo, W. H.; Zhang, X. G. Synthesis of diaryldifluoromethanes by Pd-catalyzed difluoroalkylation of arylboronic acids. *Org. Chem. Front.* **2015**, *2*, 38. (b) Guo, W. H.; Luo, Z. J.; Zeng, W. B.; Zhang, X. G. Access to difluoromethylene-skipped 1,4-diyne with gem-difluoropropargyl bromide. *ACS Catal.* **2017**, *7*, 896.