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Regioselective Synthesis of 2- or 2,7-Functionalized Pyrenes via Migration

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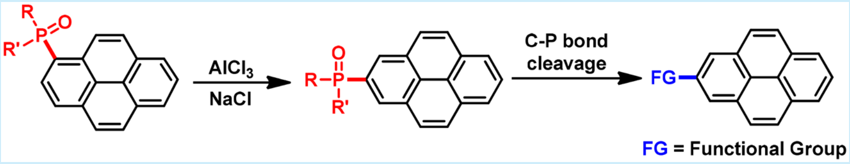
S *Supporting Information*



ABSTRACT: A simple method for the preparation of 2- or 2,7-functional pyrenes from 1- or 1,6-substituted derivatives is reported. The synthesis involves the unexpected 1,2-phosphinyl migration in an $AlCl_3$/NaCl melt. The structure of the product has been unambiguously confirmed by X-ray crystallography. We also demonstrated that further functionalization of pyrene through C−P bond activation is possible. These 2,7-positions are difficult to derivatize otherwise.

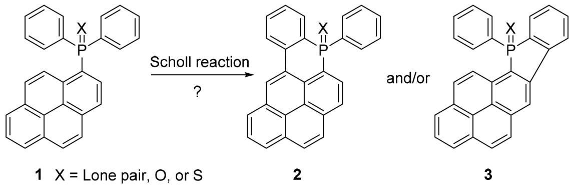
Substituting pyrene at the 2- or 2,7-positions is challenging because of the presence of the nodal plane in the HOMO and LUMO, which lies perpendicular to the molecule and passes through the 2- and 7-positions. These sites are less activated toward electrophilic substitution than the 1-, 3-, 6-, and 8-positions, except sterically driven regioselective Friedel−Crafts *tert*-butylation.[1] Indirect and multistep synthetic methods were developed for the regioselective synthesis of 2- and 7-substituted pyrenes from tetrahedropyrene,[2] pyrene−$Cr(CO)_3$ complex,[3] or well-designed biphenyl derivatives.[4] Very recently, Ir-catalyzed borylation provided a direct method to functionalize pyrene at these positions.[5]

Here we would like to report an unprecedented method to prepare 2- and 2,7-substituted pyrenes from 1- and 1,6-substituted pyrenes, respectively.

Pyrene is an important and well-studied polycyclic aromatic hydrocarbon (PAH) unit, the unique electronic and photophysical properties have led to its use in a wide variety of applications.[6] The fusion of a pyrene moiety to a π-conjugated system causes a significant alteration of physical properties.[7] Our interest in novel π-expanded organophosphorus materials and new reaction with phosphine derivatives[8] promoted us to investigate the possibility of preparation of phosphorus incorporated PAHs **2** and/or **3**[9] from an intramolecular Scholl reaction[10] with pyrene-substituted triarylphosphine **1** (Scheme 1).

To our surprise, under N_2 atmosphere, treatment of 1-pyrenylphosphine oxide **1aO** with an $AlCl_3$/NaCl melt (2.9:1) at 160 °C for 1 h gave pyrene (7%) and an unexpected 2-pyrenylphosphine oxide **4aO**, whose structure was assigned unambiguously based on the NMR spectroscopy, X-ray crystallography (see SI, Figure S1), elemental analysis, and mass spectrometry measurements. After the optimization of reaction conditions (see SI), **4aO** could be isolated in 70% yield.

Scheme 1. Proposed Synthesis of Pyrene-Fused Phosphacycle



The similar reactions were performed with other 1-pyrenylphosphine oxides. Both the open chain and cyclized phosphinyl moieties could migrate from 1- to 2-position of the pyrenyl moiety, and dimethyl-2-pyrenylphosphine oxide **4bO** (50%), bis(4-methylphenyl) (2-pyrenyl)-phosphine oxide **4dO** (48%), and 5-(2-pyrenyl)benzo[*b*]phosphindole **4eO** (63%) were obtained, respectively. 2-Pyrenylphenylphosphine oxide **4cO** can also be prepared from the corresponding 1-pyrenyl derivative. Pyrene (5−7%) was isolated from all the aforementioned reactions, but the similar reaction with tervalent phosphine **1a** (X = lone pair) provided 2-pyrenylphosphine **4a** in low yield (5%). No migration product **4aS** was obtained with 1-pyrenylphosphine sulfide (X = S) (Scheme 2). Although the reaction mechanism is unclear, involvement of an acid-promoted migration is presumed. Mechanistic study for this migration is under way.

It should be mentioned that the dual migrations are also possible. 1,6-Diphosphinylpyrene **1fO** was converted into 2,7-diphosphinylpyrene **4fO** (66%) efficiently in this molten salts system. However, the reaction with **1gO** provided the dual

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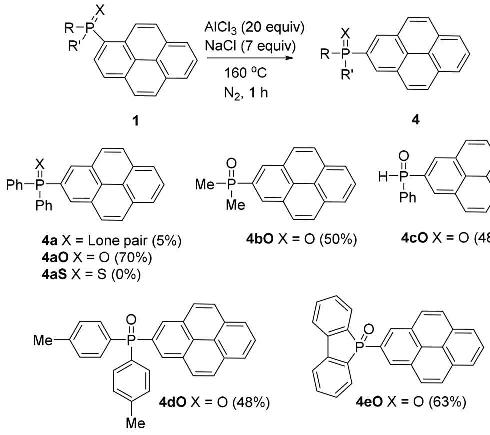
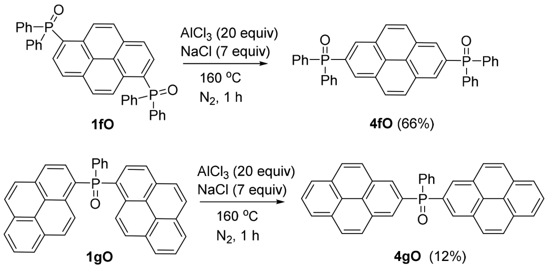
Scheme 2. Synthesis of 2-Pyrene Derivatives



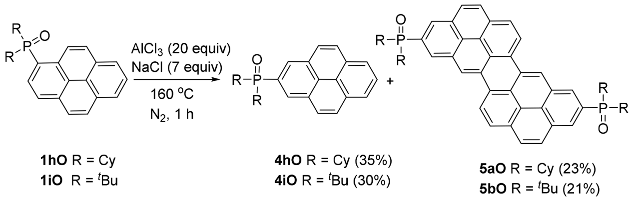
migrated product **4gO** in low yield (12%), and pyrene was isolated as a major product (35%) (Scheme 3).

Scheme 3. Synthesis of 2,7-Functionalized Pyrene and Bis(2-pyrenyl)-substituted Phosphine Oxide via Migration



Interestingly, when bulky alkyl-substituted **1hO** and **1iO** were used, besides the desired **4hO** and **4iO**, the dimerized products **5aO** and **5bO** were obtained, which were formed through the intermolecular Scholl reaction, respectively (Scheme 4). The structure of **5aO** was confirmed by X-ray crystallographic analysis (Figure 1). The reaction with purified **4hO** or **4iO** did not provide **5aO** or **5bO**, respectively. The formation of **5aO** and **5bO** might go through dimerization of the 1-pyrene derivative, followed by migration. Additional studies on the reaction mechanism are underway.

Scheme 4. Reactions with Bulky Alkyl-substituted Phosphine Oxides



The intramolecular coupling reaction was realized with diphenyl(1-pyrenyl)phosphonate **1jO**. The reaction took place between one of the phenoxy groups and position C10 of the pyrenyl moiety to give a pyrene-fused seven-membered phosphacycle **6** (Scheme 5, Figure 2).

The UV–vis absorption and fluorescence spectra of representative precursors and the corresponding migrated products in CH_2Cl_2 are summarized in Figure 3 and Table 1.

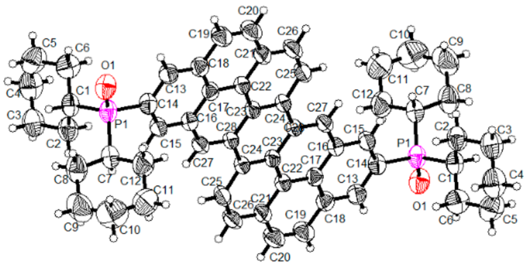
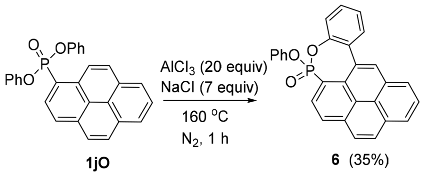


Figure 1. X-ray crystal structure of **5aO**. The level set for thermal ellipsoids of all atoms is 50%. Main bond lengths (Å) and angles (deg): P1–O1 1.484(2), C14–P1 1.813(3), C1–P1 1.822(3), C13–C14 1.392(4), C7–P1–C14 105.14(14), C1–P1–C14 107.08(13). CCDC reference number: 1830073.

Scheme 5. Synthesis of Pyrene-fused Seven-membered Phosphacycle



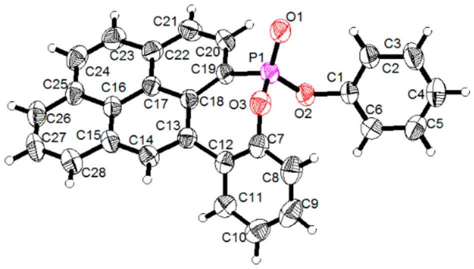


Figure 2. X-ray crystal structure of **6**. The level set for thermal ellipsoids of all atoms is 50%. Main bond lengths (Å) and angles (deg): P1–O1 1.461(2), P1–O2 1.5964(18), P1–O3 1.588(2), C1–O2 1.407(3), C7–O3 1.401(3), C2–C1–O2 122.3(2), C1–O2–P1 125.86(16), O1–P1–O3 110.32(12), P1–O3–C7 118.34(15). CCDC reference number: 1830074.

The absorption spectra of migrated products show blue shifts in comparison to the precursors, while the emission spectra are slightly red-shifted. Compared with **4hO**, a significant red shift was observed in **5aO**, indicating that the π-conjugation is significantly extended via dimerization. The fluorescence quantum yields (Φ_f) of these compounds range from 0.37 to 0.93. Higher luminescence efficiencies were observed with 1-pyrenylphosphine oxides than the corresponding migrated products (Table 1).

It should be noticed that 2-pyrenylphosphine derivatives can be used as a 2-pyrenyl building block to synthesize various 2-pyrenyl-substituted compounds via C–P bond cleavage.[11] For example, **4a** and **8** could be synthesized easily from **4aO** (see SI). 2-Alkenylpyrene **7** was prepared through the Pd-catalyzed C–P cleavage of **4a**.[12] 2-Arylpyrene **9** and 2-pyrenemethanol **10** were synthesized through Pd-catalyzed[13] or $CsCO_3$-mediated[14] C–P bond activation of 2-pyrenylphosphonium **8**, respectively (Scheme 6).

The resulting 2-pyrenylphosphine derivatives were used to synthesize π-conjugated phosphacycles, which might be interesting for material science.[9] 2-Pyrenylphenylphosphine oxide **4cO** was converted into a pyrene-fused phosphole oxide

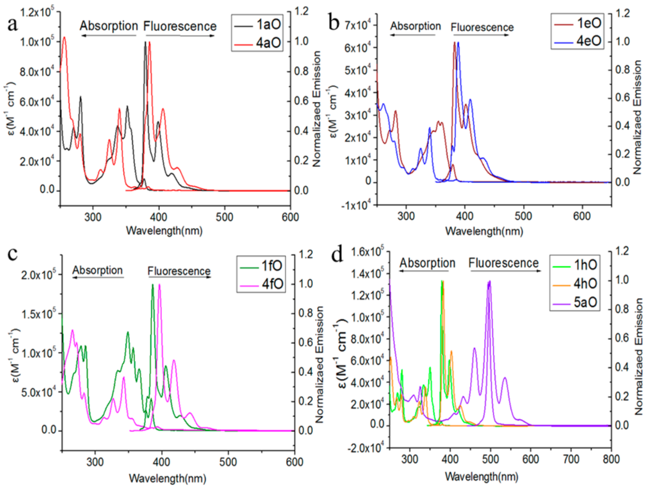


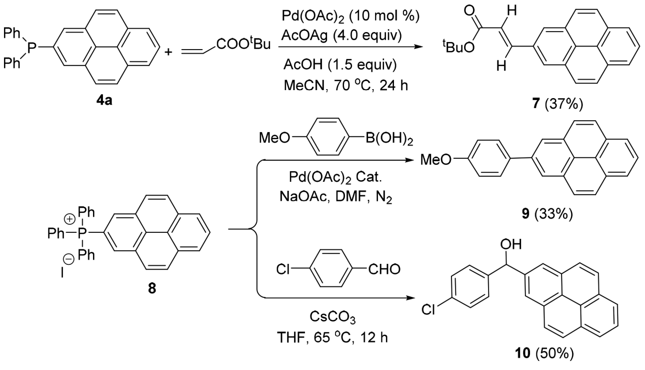
Figure 3. (a) UV−vis absorption and fluorescence spectra of the **1aO** and **4aO** in CH_2Cl_2 at rt. (b) UV−vis absorption and fluorescence spectra of the **1eO** and **4eO** in CH_2Cl_2 at rt. (c) UV−vis absorption and fluorescence spectra of the **1fO** and **4fO** in CH_2Cl_2 at rt. (d) UV−vis absorption and fluorescence spectra of the **1hO**, **4hO**, and **5aO** in CH_2Cl_2 at rt.

Table 1. Photophysical Data

compd	λ_{abs} (nm)[a]	λ_{ex} (nm)[a]	λ_{em} (nm)[a]	Φ_f[b]
1aO	323,337,352	352	379,398,420	0.93
4aO	312,325,341	341	386,406,428	0.76
1eO	345,355,360,379	345	382,401	0.70
4eO	312,325,341	341	389,409,432	0.37
1fO	349,357,366,375,384	357	386,406,427	0.72
4fO	313,327,342	342	396,418,442	0.60
1hO	320,333,350	333	379,398,420	0.57
4hO	309,322,338	338	382,403,424	0.41
5aO	325,432,461,494	432	498,535	0.56

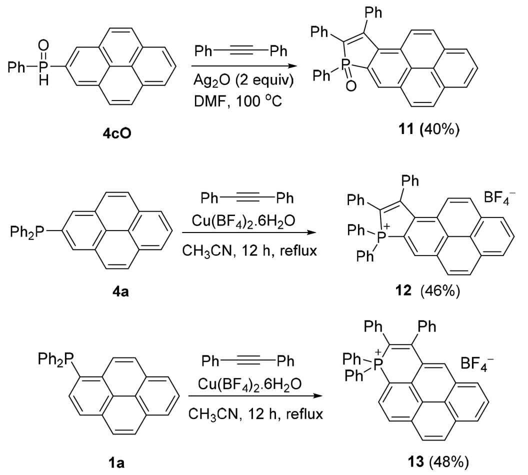
[a]Measured in CH_2Cl_2 (5×10^{-6} M). [b]Measured relative to quinine sulfate (H_2SO_4, 0.1 M), ±15%.

Scheme 6. Synthesis of 2-Pyrenyl Compounds via C−P Bond Cleavage



11 (for crystal structure, see SI, Figure S4) directly through silver-mediated oxidative C−H/P-H functionalization.[15] Following Wang's Cu-mediated annulation,[16] **4a** was transformed into a pyrene-fused phosphindolium **12** (for crystal structure, see SI, Figure S5). For the comparison, under the same conditions, the reaction with **1a** gave a six-membered phosphacycle **13** (Scheme 7, Figure 4). This selectivity might be due to the inertness of position C2.[1]

Scheme 7. Synthesis of Pyrene-fused π-Conjugated Phosphacycles



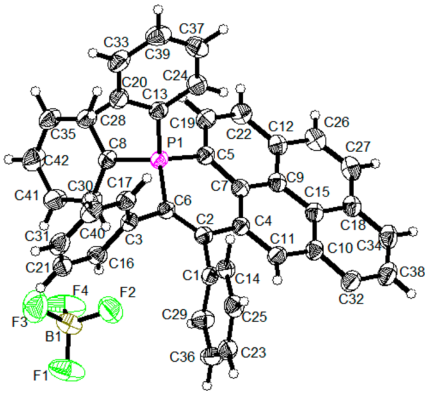


Figure 4. X-ray crystal structure of **13**. The level set for thermal ellipsoids of all atoms is 50%. Main bond lengths (Å) and angles (deg): P1−C5 1.775(2), P1−C6 1.7822(19), P1−C8 1.791(2), C5−P1−C6 106.80(9), C5−P1−C8 108.57(9), C5−P1−C13 109.32(9). CCDC reference number: 1857706.

In conclusion, the regioselective synthesis of 2- or 2,7-substituted pyrenes was achieved through the migration of related 1 or 1,6-substituted derivatives, respectively. The further C−P bond cleavage provides considerable utility for pyrene functionalizations. The further elucidation of the migration mechanism and the development of π-conjugated organophosphorus functional materials using this method are underway in our laboratory.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.8b03270.

Experimental procedure and characterization of all new compounds (PDF)

Accession Codes

CCDC 1586367, 1830073−1830074, 1857706, 1861056, and 1866548 contain 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

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Notes

The authors declare no competing financial interest.

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