

# Preparation of Alkyl Indium Reagents by Iodine-Catalyzed Direct Indium Insertion and Their Applications in Cross-Coupling Reactions

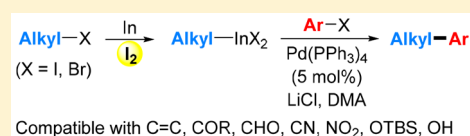
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## Supporting Information

**ABSTRACT:** An efficient method for the synthesis of alkyl indium reagent by means of an iodine-catalyzed direct indium insertion into alkyl iodide in THF is reported. The thus-generated alkyl indium reagents effectively underwent Pd-catalyzed cross-coupling reactions with various aryl halides, exhibiting good compatibility to a variety of sensitive functional groups. By replacing THF with DMA and using 0.75 equiv of iodine, less reactive alkyl bromide could be used as substrate for indium insertion with equal ease.



Organometallic reagents have revolutionized modern organic synthesis.<sup>1</sup> The past several decades have witnessed the fast development of organoindium reagents and their wide applications in organic synthesis and material science.<sup>2</sup> The intrinsically mild reactivity of organoindium reagents enables them to undergo various organic transformations with good functional group tolerance and sometimes markedly enhanced chemo- and stereoselectivities, rendering them appealing alternatives to other more reactive but moisture-sensitive organometallics such as organolithium, organomagnesium, organoaluminum, and organozinc reagents. Till now, some representative organoindium reagents, such as allylindium,<sup>3</sup> propargylindium,<sup>4</sup> and indium enolate,<sup>5</sup> which can be readily and *in situ* prepared by mixing indium with respective organic halides, have found extensive applications in various organic transformations, as demonstrated by Araki, Chan, Li, Paquette, Whitesides, Lee, Baba, our group, and others. Besides, triorganoindium reagents (R<sub>3</sub>In),<sup>6</sup> which can be easily accessed by means of the transmetalation of indium(III) halides with either organolithium or organomagnesium reagents, have also found broad utilities in organic synthesis, especially in transition metal-catalyzed cross-coupling reactions. In contrast, the preparation of aryl,<sup>7</sup> alkenyl,<sup>8</sup> benzyl,<sup>9</sup> and alkyl<sup>10</sup> indium reagents as well as their applications in organic synthesis has not aroused too much attention from the synthetic community until it was discovered that the use of stoichiometric amounts of lithium salt<sup>11</sup> or copper salt<sup>10a-c</sup> could effectively facilitate the direct insertion of indium powder into the corresponding organic halides within recent 10 years, as revealed by Knochel, Lee, Minehan, Yoshika, our group, and others.<sup>12</sup> In our continued endeavor to seek an efficient method for the synthesis of organoindium reagent as well as their synthetic utilities, herein we report that a catalytic amount of iodide<sup>13</sup> (20 mol %) was capable of

efficiently catalyzing the direct insertion of indium into alkyl iodides, producing the desired alkyl indium reagent with high efficiency. The thus-generated alkyl indium reagents readily underwent palladium-catalyzed cross-coupling reactions with a wide variety of aryl halides to produce the cross-coupled products in moderate to good yields, exhibiting excellent functional group compatibility.

Initially, we optimized the reaction conditions by using (2-iodoethyl)benzene (**1a**) as substrate in the presence of different equivalents of indium powder and iodine in THF at 60 °C for 24 h. As shown in Table 1, when 2 equiv of indium and 1 equiv of iodine were used, the formation of 90% NMR yield of alkyl indium reagent was detected (entry 1), as revealed by <sup>1</sup>H NMR analysis of the crude reaction mixture

**Table 1. Optimization of Reaction Conditions<sup>a</sup>**

entry	x	y	yield (%) <sup>b</sup>
1	2	1	90
2	2	0.5	84
3	2	0.1	82
4	1.5	0.1	80
5	1	0.1	55

<sup>a</sup>The insertion was performed at 60 °C for 24 h by using (2-iodoethyl)benzene (**1a**, 1 mmol), indium powder (1–2 equiv), and iodine (0.1–1 equiv) in THF (2 mL). <sup>b</sup>The yield was determined by <sup>1</sup>H NMR analysis of the crude reaction mixture by using 1,4-dimethoxybenzene as an internal standard.

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against an internal standard of 1,4-dimethoxybenzene. Gratifyingly, when the amount of iodine decreased from 1 equiv to 0.5 or 0.1 equiv, the insertion reaction proceeded with almost equal success to produce the corresponding alkyl indium compound in 84% and 82% NMR yields (entries 2 and 3), indicating that a catalytic amount of iodine was sufficient to catalyze the insertion reaction. In addition, when 0.1 equiv of iodine was used and lowered the amount of indium powder from 2 equiv to 1.5 equiv, the reaction worked equally well to give the desired product in 80% NMR yield (entry 4). However, when 1.0 equiv of indium was employed under the same reaction conditions, the product yield decreased sharply (55%, entry 5).









Subsequently, the substrate scope of the present reaction was examined by utilizing various aryl iodides as substrates. As listed in Table 2, both the indium insertion reaction and the ensuing cross-coupling reaction with a spectrum of aryl halides proceeded efficiently under optimized reaction conditions to afford the cross-coupling products **3a–n** in moderate to good yields (entries 1–14). In addition to aryl halides, heteroaryl iodides **2k**, **2m**, and **2n** containing oxygen or nitrogen atom worked equally well under the well-established conditions to furnish the target products in good yields (entries 11, 13, and 14). Besides aryl iodides, less reactive aryl bromides **2g/2i** and chloride **2j** were also proven to be effective coupling partners for the present reaction, generating the desired products **3g**, **3i**, and **3j** in moderate yields (entries 7, 9, and 10). Especially noteworthy is that the reaction exhibited remarkable tolerance to a range of sensitive functional groups, such as acetyl, nitrile, nitro, ester, and aldehyde (entries 1–11), allowing them amenable for downstream chemical modifications.

To further demonstrate the generality of the method, a number of alkyl iodides were explored. As summarized in Table 3, an array of structurally varied alkyl iodides were effectively transformed into the anticipated alkyl indium reagents, which, upon undergoing palladium-catalyzed cross-coupling reactions with aryl iodide **2a**, furnished the coupling products **4b–k** in 46–97% yields (entries 1–10). Similarly, the mildness of the formed alkyl indium reagents entailed the presence of various functional groups in the substrates including C=C (**1e**), nitrile (**1f**), ester (**1g**), amide (**1h**), OTBS (**1i**), and even a hydroxyl group (**1j**). Moreover, the approach could also be extended to the use of secondary iodide **1k** as starting material, delivering the corresponding product **4k** in an acceptable yield of 46% (entry 10).

However, when the optimized reaction conditions were applied to the indium insertion into less reactive (2-bromoethyl)benzene (**5a**) in the presence of 0.1 equiv of iodine in THF, the reaction proceeded sluggishly to yield the alkyl indium reagent in <5% yield (Scheme 1). To our delight, when 0.75 equiv of iodine was introduced into the reaction system, 47% NMR yield of the alkyl metallic species was obtained. Remarkably, the product yield could be further improved to 67% when the insertion reaction was performed under identical reaction conditions by using more polar DMA as reaction solvent.

Following the successful results with the use of alkyl bromide **5a** as substrate, the substrate scope of the method was surveyed by employing a variety of structurally different substituted alkyl bromides. As shown in Table 4, various alkyl bromides were also capable of efficiently participating in the indium insertion reaction as well as the following cross-coupling reaction with aryl iodide **2a**, leading to the cross-

**Table 2. Substrate Scope Study by Using Various Aryl Halides<sup>a</sup>**

entry	substrate	product	yield (%) <sup>b</sup>
	$\text{Ph-CH}_2\text{-CH}_2\text{-I} \xrightarrow[2. \text{ArX (2), Pd(PPh}_3)_4, \text{LiCl, DMA, 100 }^\circ\text{C, 12 h}]{1. \text{In, I}_2, \text{THF, 60 }^\circ\text{C, 24 h}} \text{Ph-CH}_2\text{-CH}_2\text{-Ar}$		
1		<b>3a</b>	96
2	<b>2b</b> (R = CN)	<b>3b</b>	96
3	<b>2c</b> (R = NO <sub>2</sub> )	<b>3c</b>	85
4		<b>3d</b>	95
5	<b>2e</b>	<b>3e</b>	97
6		<b>3f</b>	65
7	<b>2g</b> (X = Br)	<b>3g</b>	48
8		<b>3h</b>	97
9	<b>2i</b> (X = Br)	<b>3i</b>	67
10	<b>2j</b> (X = Cl)	<b>3j</b>	49
11		<b>3k</b>	78
12		<b>3l</b>	88
13		<b>3m</b>	82
14		<b>3n</b>	77

<sup>a</sup>See the Supporting Information for detailed reaction conditions.

<sup>b</sup>Yield of isolated product based on aryl halides **2a–n** as limiting reagent.

coupled products **6a–h** in 57–93% yields (entries 1–8). In a same manner, excellent compatibility of the reaction to various functional groups (e.g., C=C, OH, CN, CONR<sub>2</sub>, and Ac) was also observed.

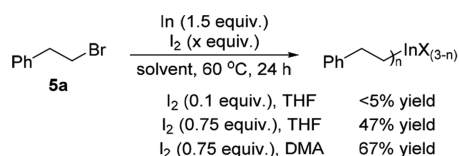
We speculated that iodine might react with indium to form indium monoiodide (InI) which presumably facilitates the subsequent insertion reaction. It was observed that, when iodine was mixed with indium in THF at 60 °C with stirring, the color of iodine disappeared gradually after several minutes. In addition, when the insertion reaction using (2-iodoethyl)benzene (**1a**) was performed in the presence of 1.5 equiv of In and 0.75 equiv of I<sub>2</sub> (which might lead to the formation of 1.5 equiv of InI) under optimized reaction conditions, the formation of only one type of alkyl indium reagent was observed. We believed that the formed alkyl indium reagent

Table 3. Substrate Scope Study by Using Various Alkyl Iodides<sup>a</sup>

entry	substrate	product	yield (%) <sup>b</sup>
1			79
2			73
3			67
4			97
5			79
6			64
7			75
8			48
9			49
10			46

<sup>a</sup>See the Supporting Information for detailed reaction conditions.  
<sup>b</sup>Yield of isolated product based on aryl iodide 2a as limiting reagent.

### Scheme 1. Preparation of Alkyl Indium Reagent by Using (2-Bromoethyl)benzene (5a) as Substrate



should be an alkyl indium dihalide ( $\text{RInX}_2$ ) on the basis of the following equation:  $\text{RI} + \text{InI} = \text{RInI}_2$ . In contrast, when the model reaction was conducted in the presence of 1.5 equiv of In and 0.1 equiv of  $\text{I}_2$  under established reaction conditions (entry 4, Table 1), the generation of two types of alkyl indium species was detected on the basis of  $^1\text{H}$  NMR analysis, which should be the mixture of an alkyl indium dihalide ( $\text{RInX}_2$ ) and a dialkyl indium halide ( $\text{R}_2\text{InX}$ ).

In a nutshell, an efficient method for the synthesis of alkyl indium reagents by means of an iodine-catalyzed indium insertion into alkyl iodides has been achieved. After undergoing Pd-catalyzed cross-coupling reactions with various aryl halides as coupling partners, the corresponding products were

Table 4. Substrate Scope Study by Using Various Alkyl Bromides<sup>a</sup>

entry	substrate	product	yield (%) <sup>b</sup>
1			83
2			73
3			71
4			93
5			72
6			85
7			57
8			81

<sup>a</sup>See the Supporting Information for detailed reaction conditions.  
<sup>b</sup>Yield of isolated product based on aryl iodide 2a as limiting reagent.

obtained in modest to good yields. A variety of sensitive functional groups, including cyano, nitro, amide, ester, aldehyde, and hydroxyl group, were well tolerated as a result of the mildness of the reaction conditions as well as the formed alkyl indium reagents. Moreover, by replacing THF with DMA and using 0.75 equiv of iodine, less reactive alkyl bromides could be used as substrates for indium insertion with equal ease.

## EXPERIMENTAL SECTION

**General Information.** Commercially available alkyl halides and aryl halides were used without further purification. Starting material of 1-(4-(2-bromoethyl)phenyl)ethan-1-one (**5h**)<sup>14</sup> was prepared according to a reported method. Analytical grade THF and DMA were used in all the reactions (without the need to exclude air and moisture) without purification. Indium powder, iodine, palladium catalyst, and lithium chloride were purchased from chemical companies and used directly without further purification. Analytical thin layer chromatography (TLC) was performed using silica gel plate (0.2 mm thickness). Subsequent to elution, plates were visualized using UV radiation (254 nm). Flash chromatography was performed using Merck silica gel (200–300 mesh) for column chromatography with freshly distilled solvents. Columns were typically packed as slurry and equilibrated with the appropriate solvent system prior to use. IR spectra were recorded on an FT-IR spectrophotometer using KBr optics.  $^1\text{H}$  and  $^{13}\text{C}$  NMR spectra were recorded in  $\text{CDCl}_3$  on JEOL 400 MHz spectrometers. Tetramethylsilane (TMS) served as internal standard for  $^1\text{H}$  and  $^{13}\text{C}$  NMR analysis. High resolution mass spectra (HRMS) were recorded on a Waters Q-TOF Premier Spectrometer (ESI or EI source).

**General Procedure for the Synthesis of Alkyl Indium Reagents from Alkyl Iodides and Palladium-Catalyzed Cross-Coupling Reaction with Aryl Halides (Tables 2 and 3).**



**The Insertion Step.** Alkyl iodide (1 mmol), indium powder (172.2 mg, 1.5 mmol), iodine (25.4 mg, 0.1 mmol), and analytical grade THF (2 mL) were added in a flask equipped with a septum and a magnetic stir bar. The reaction mixture was vigorously stirred at 60 °C for 24 h. Then the upper clear solution was carefully separated from the bottom black precipitate by centrifugation. The remaining black precipitate was additionally stirred with THF (3 mL), and the THF layer was carefully separated from the bottom precipitate by pipet. The combined organic layers were concentrated under vacuum. The crude mixture was directly used in the next step without further purification.

**The Cross-Coupling Step.** To the above residue were added aryl halide (0.7 mmol), LiCl (84.8 mg, 2 mmol), Pd(PPh<sub>3</sub>)<sub>4</sub> (57.8 mg, 0.05 mmol), and DMA (2 mL), and the reaction mixture was stirred at 100 °C for 12 h. Upon completion of the reaction, the reaction mixture was directly purified by flash silica gel column chromatography using petroleum ether and ethyl acetate as eluant to afford the pure products (petroleum ether:EtOAc = 30:1 for **3a–3j**, **4b–4e**, **4i**, and **4k**; petroleum ether:EtOAc = 15:1 for **3k**; pure petroleum ether for **3l**; petroleum ether:EtOAc = 4:1 for **3m**; petroleum ether:EtOAc = 3:1 for **3n** and **4j**; petroleum ether:EtOAc = 10:1 for **4f–4g**; petroleum ether:EtOAc = 1:1 for **4h**).

**General Procedure for the Synthesis of Alkyl Indium Reagents from Alkyl Bromides and Palladium-Catalyzed Cross-Coupling Reaction with Aryl Halides (Table 4).** **The Insertion Step 1.** Alkyl bromide (1 mmol), indium powder (172.2 mg, 1.5 mmol), iodine (172.2 mg, 0.75 mmol), and analytical grade DMA (2 mL) were added in a flask equipped with a septum and a magnetic stir bar. The reaction mixture was vigorously stirred at 60 °C for 24 h. Then the upper clear solution was carefully separated from the bottom black precipitate by centrifugation. The remaining black precipitate was additionally stirred with DMA (1 mL), and the DMA layer was carefully separated from the bottom precipitate by pipet. The crude mixture was directly used in the next step without further purification.

**The Cross-Coupling Step 2.** To the above DMA solution were added 1-(4-iodophenyl)ethan-1-one (172.2 mg, 0.7 mmol), LiCl (84.8 mg, 2 mmol), and Pd(PPh<sub>3</sub>)<sub>4</sub> (57.8 mg, 0.05 mmol), and the reaction mixture was stirred at 100 °C for 12 h. Upon completion of the reaction, the reaction mixture was directly purified by flash silica gel column chromatography using petroleum ether and ethyl acetate as eluant to afford the pure products (petroleum ether:EtOAc = 30:1 for **6a–6d**; petroleum ether:EtOAc = 3:1 for **6e**; petroleum ether:EtOAc = 10:1 for **6f** and **6h**; petroleum ether:EtOAc = 1:1 for **6g**).

**1-(4-Phenethylphenyl)ethan-1-one (3a, 6a).**<sup>10d</sup> 150.7 mg, 130.7 mg. Yield = 96%, 83%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.78 (d, J = 7.8 Hz, 2H), 7.21–7.06 (m, 7H), 2.92–2.82 (m, 4H), 2.49 (s, 3H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 197.8, 147.4, 141.0, 135.0, 128.7, 128.5, 128.4, 128.3, 126.0, 37.8, 37.4, 26.5 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>16</sub>H<sub>17</sub>O: 225.1274, found: 225.1284. FTIR (KBr, neat): ν 1676 cm<sup>-1</sup>.

**4-Phenethylbenzotrile (3b).**<sup>10d</sup> 139.6 mg. Yield = 96%. Yellow solid. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.40–7.38 (m, 2H), 7.17–7.14 (m, 2H), 7.11–7.06 (m, 3H), 7.02–7.00 (m, 2H), 2.87–2.83 (m, 2H), 2.81–2.77 (m, 2H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 147.2, 140.5, 132.1, 129.3, 128.4, 128.4, 126.2, 119.1, 109.7, 37.9, 37.2 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>15</sub>H<sub>14</sub>N: 208.1121, found: 208.1126. FTIR (KBr, neat): ν 2226 cm<sup>-1</sup>.

**1-Nitro-4-phenethylbenzene (3c).**<sup>10d</sup> 135.3 mg. Yield = 85%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.99–7.96 (m, 2H), 7.18–7.13 (m, 4H), 7.10–7.06 (m, 1H), 7.03–7.01 (m, 2H), 2.93–2.88 (m, 2H), 2.85–2.80 (m, 2H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 149.4, 146.4, 140.4, 129.3, 128.5, 128.4, 126.3, 123.6, 37.7, 37.2 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>14</sub>H<sub>14</sub>NO<sub>2</sub>: 228.1019, found: 228.1024. FTIR (KBr, neat): ν 1514 cm<sup>-1</sup>.

**1-Nitro-3-phenethylbenzene (3d).**<sup>10d</sup> 150.9 mg. Yield = 95%. Yellow solid. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.91–7.90 (m, 2H), 7.33–7.25 (m, 2H), 7.18–7.14 (m, 2H), 7.10–7.02 (m, 3H), 2.92–2.88 (m, 2H), 2.84–2.80 (m, 2H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz,

CDCl<sub>3</sub>): δ 148.1, 143.5, 140.4, 134.8, 129.1, 128.4, 128.4, 126.2, 123.2, 121.1, 37.3, 37.3 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>14</sub>H<sub>14</sub>NO<sub>2</sub>: 228.1019, found: 228.1024. FTIR (KBr, neat): ν 1526 cm<sup>-1</sup>.

**1-Nitro-2-phenethylbenzene (3e).**<sup>10d</sup> 154.1 mg. Yield = 97%. Yellow solid. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.78 (dd, J = 8.2, 1.3 Hz, 1H), 7.35 (td, J = 7.5, 1.3 Hz, 1H), 7.23–7.06 (m, 7H), 3.07–3.03 (m, 2H), 2.85–2.81 (m, 2H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 149.3, 140.9, 136.6, 132.9, 132.2, 128.5, 128.4, 127.2, 126.2, 124.8, 37.0, 35.5 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>14</sub>H<sub>14</sub>NO<sub>2</sub>: 228.1019, found: 228.1024. FTIR (KBr, neat): ν 1526 cm<sup>-1</sup>.

**Ethyl 4-Phenethylbenzoate (3f, 3g).**<sup>10d</sup> 115.5 mg, 85.4 mg. Yield = 65%, 48%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.88–7.85 (m, 2H), 7.20–7.05 (m, 7H), 4.27 (q, J = 7.2 Hz, 2H), 2.91–2.81 (m, 4H), 1.30 (t, J = 7.1 Hz, 3H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 166.6, 147.0, 141.1, 129.6, 128.5, 128.4, 128.3, 128.2, 126.0, 60.8, 37.8, 37.4, 14.3 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>17</sub>H<sub>19</sub>O<sub>2</sub>: 255.1380, found: 255.1385. FTIR (KBr, neat): ν 1713 cm<sup>-1</sup>.

**4-Phenethylbenzaldehyde (3h, 3i, 3j).**<sup>10d</sup> 142.3 mg, 98.6 mg, 71.8 mg. Yield = 97%, 67%, 49%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 9.85 (s, 1H), 7.68 (d, J = 7.1 Hz, 2H), 7.21–7.03 (m, 7H), 2.92–2.81 (m, 4H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 191.8, 148.9, 140.7, 134.4, 129.8, 129.0, 128.3, 128.3, 126.0, 37.9, 37.2 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>15</sub>H<sub>15</sub>O: 211.1117, found: 211.1123. FTIR (KBr, neat): ν 1701 cm<sup>-1</sup>.

**5-Phenethylfuran-2-carbaldehyde (3k).**<sup>10d</sup> 108.9 mg. Yield = 78%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 9.41 (s, 1H), 7.20–7.15 (m, 2H), 7.11–7.03 (m, 4H), 6.08 (d, J = 3.5 Hz, 1H), 2.92 (s, 4H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 176.9, 162.5, 151.7, 140.1, 128.4, 128.2, 126.3, 123.6, 109.1, 33.6, 30.1 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>13</sub>H<sub>13</sub>O<sub>2</sub>: 201.0910, found: 201.0916. FTIR (KBr, neat): ν 1677 cm<sup>-1</sup>.

**1-Phenethylnaphthalene (3l).**<sup>10d</sup> 143.0 mg. Yield = 88%. Colorless oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 8.01 (d, J = 8.3 Hz, 1H), 7.77 (d, J = 7.9 Hz, 1H), 7.63 (d, J = 8.1 Hz, 1H), 7.45–7.37 (m, 2H), 7.31–7.27 (m, 1H), 7.24–7.10 (m, 6H), 3.30–3.26 (m, 2H), 2.98–2.94 (m, 2H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 142.0, 137.8, 133.8, 131.7, 128.8, 128.4, 126.7, 126.0, 126.0, 125.8, 125.5, 125.4, 123.6, 37.1, 35.1 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>18</sub>H<sub>17</sub>: 233.1325, found: 233.1330.

**3-Phenethylpyridine (3m).**<sup>10d</sup> 105.7 mg. Yield = 82%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 8.32 (s, 2H), 7.30 (dt, J = 7.8, 1.7 Hz, 1H), 7.16 (tt, J = 8.3, 1.5 Hz, 2H), 7.10–7.02 (m, 4H), 2.79 (s, 4H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 149.8, 147.3, 140.7, 136.8, 136.0, 128.4, 128.4, 126.1, 123.2, 37.4, 34.9 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>13</sub>H<sub>14</sub>N: 184.1121, found: 184.1126.

**2-Phenethylpyrazine (3n).**<sup>10d</sup> 99.5 mg. Yield = 77%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 8.41–8.40 (m, 1H), 8.29 (s, 1H), 8.25 (s, 1H), 7.19–7.06 (m, 5H), 3.04–2.94 (m, 4H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 156.7, 144.7, 144.1, 142.3, 140.7, 128.5, 128.4, 126.2, 37.2, 35.4 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>12</sub>H<sub>13</sub>N<sub>2</sub>: 185.1073, found: 185.1079. FTIR (KBr, neat): ν 3027, 2927, 1430 cm<sup>-1</sup>.

**1-(4-(3-Phenylpropyl)phenyl)ethan-1-one (4b, 6b).**<sup>10d</sup> 131.4 mg, 121.1 mg. Yield = 79%, 73%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.76 (d, J = 7.4 Hz, 2H), 7.18–7.12 (m, 4H), 7.08–7.04 (m, 3H), 2.58–2.50 (m, 4H), 2.43 (s, 3H), 1.88–1.80 (m, 2H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 197.6, 147.9, 141.7, 134.8, 128.5, 128.3, 128.2, 128.2, 125.7, 35.2, 35.2, 32.4, 26.4 ppm. HRMS (ESI, m/z): [M + H]<sup>+</sup>, calcd. for C<sub>17</sub>H<sub>19</sub>O: 239.1430, found: 239.1430. FTIR (KBr, neat): ν 1682 cm<sup>-1</sup>.

**1-(4-Nonylphenyl)ethan-1-one (4c).**<sup>10d</sup> 126.5 mg. Yield = 73%. Yellow oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.79 (d, J = 8.2 Hz, 2H), 7.17 (d, J = 8.2 Hz, 2H), 2.59–2.55 (m, 2H), 2.49 (s, 3H), 1.58–1.50 (m, 2H), 1.23–1.18 (m, 11H), 0.79 (t, J = 6.8 Hz, 4H) ppm. <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, CDCl<sub>3</sub>): δ 197.6, 148.7, 134.7, 128.5, 128.3, 35.9, 31.8, 31.1, 29.4, 29.4, 29.2, 29.2, 26.4, 22.6, 14.0 ppm. HRMS (ESI,

$m/z$ ):  $[M + H]^+$ , calcd. for  $C_{17}H_{27}O$ : 247.2056, found: 247.2062. FTIR (KBr, neat):  $\nu$  1684  $cm^{-1}$ .

**1-(4-Hexylphenyl)ethan-1-one (4d, 6c).**<sup>10d</sup> 95.9 mg, 101.2 mg. Yield = 67%, 71%. Colorless oil.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.80–7.77 (m, 2H), 7.18–7.15 (m, 2H), 2.58–2.54 (m, 2H), 2.47 (s, 3H), 1.56–1.49 (m, 2H), 1.26–1.17 (m, 6H), 0.80–0.77 (m, 3H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  197.9, 148.8, 134.8, 128.6, 128.4, 36.0, 31.6, 31.1, 28.9, 26.5, 22.5, 14.1 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{14}H_{21}O$ : 205.1587, found: 205.1590. FTIR (KBr, neat):  $\nu$  1683  $cm^{-1}$ .

**1-(4-(Hex-5-en-1-yl)phenyl)ethan-1-one (4e, 6d).**<sup>15</sup> 137.8 mg, 131.8 mg. Yield = 97%, 93%. Yellow oil.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.89–7.86 (m, 2H), 7.27–7.24 (m, 2H), 5.79 (ddt,  $J$  = 16.9, 10.2, 6.7 Hz, 1H), 5.00 (dq,  $J$  = 17.1, 1.7 Hz, 1H), 4.94 (ddt,  $J$  = 10.2, 2.2, 1.2 Hz, 1H), 2.68–2.64 (m, 2H), 2.57 (s, 3H), 2.11–2.05 (m, 2H), 1.72–1.57 (m, 2H), 1.47–1.39 (m, 2H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  197.8, 148.5, 138.5, 134.8, 128.5, 128.4, 114.5, 35.7, 33.5, 30.4, 28.3, 26.5 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{14}H_{19}O$ : 203.1430, found: 203.1436. FTIR (KBr, neat):  $\nu$  1683  $cm^{-1}$ .

**4-(4-Acetylphenyl)butanenitrile (4f, 6f).**<sup>10d</sup> 104.1 mg, 111.1 mg. Yield = 79%, 85%. Brown solid.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.84–7.82 (m, 2H), 7.22–7.20 (m, 2H), 2.77 (t,  $J$  = 7.5 Hz, 2H), 2.51 (s, 3H), 2.27 (t,  $J$  = 7.0 Hz, 2H), 1.96–1.89 (m, 2H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  197.6, 145.3, 135.5, 128.7, 128.6, 119.1, 34.2, 26.5, 26.4, 16.3 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{12}H_{14}NO$ : 188.1070, found: 188.1078. FTIR (KBr, neat):  $\nu$  2246, 1682  $cm^{-1}$ .

**Ethyl 4-(4-Acetylphenyl)butanoate (4g).**<sup>10d</sup> 105.2 mg. Yield = 64%. Colorless oil.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.89 (dd,  $J$  = 8.1, 1.5 Hz, 2H), 7.28 (d,  $J$  = 6.8 Hz, 2H), 4.16–4.10 (m, 2H), 2.72 (t,  $J$  = 7.6 Hz, 2H), 2.59 (s, 3H), 2.34–2.31 (m, 2H), 2.01–1.94 (m, 2H), 1.28–1.24 (m, 3H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  197.8, 173.2, 147.2, 135.2, 128.7, 128.5, 60.3, 35.1, 33.5, 26.5, 26.1, 14.2 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{14}H_{19}O_3$ : 235.1329, found: 235.1328. FTIR (KBr, neat):  $\nu$  1732, 1683  $cm^{-1}$ .

**2-(3-(4-Acetylphenyl)propyl)isoindoline-1,3-dione (4h, 6g).**<sup>16</sup> 160.6 mg, 123.3 mg. Yield = 75%, 57%. Yellow solid.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.74–7.68 (m, 4H), 7.62–7.59 (m, 2H), 7.19–7.17 (m, 2H), 3.64 (t,  $J$  = 7.0 Hz, 2H), 2.65 (t,  $J$  = 7.7 Hz, 2H), 2.44 (s, 3H), 2.00–1.93 (m, 2H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  197.5, 168.2, 146.6, 134.9, 133.8, 131.8, 128.4, 128.3, 123.0, 37.4, 33.0, 29.1, 26.4 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{19}H_{18}NO_3$ : 308.1281, found: 308.1287. FTIR (KBr, neat):  $\nu$  1720, 1673  $cm^{-1}$ .

**1-(4-(6-(tert-Butyldimethylsilyloxy)hexyl)phenyl)ethan-1-one (4i).**<sup>10d</sup> 111.3 mg. Yield = 48%. Yellow oil.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.79 (d,  $J$  = 8.2 Hz, 2H), 7.17 (d,  $J$  = 8.1 Hz, 2H), 3.51 (t,  $J$  = 6.5 Hz, 2H), 2.59–2.55 (m, 2H), 2.49 (s, 3H), 1.59–1.52 (m, 2H), 1.46–1.39 (m, 2H), 1.28–1.26 (m, 4H), 0.81 (s, 9H), –0.04 (s, 6H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  197.9, 148.7, 134.9, 128.6, 128.5, 63.2, 35.9, 32.7, 31.1, 29.0, 26.6, 26.0, 25.6, 18.4, –5.3 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{20}H_{35}O_2Si$ : 335.2401, found: 335.2401. FTIR (KBr, neat):  $\nu$  1685  $cm^{-1}$ .

**1-(4-(3-Hydroxypropyl)phenyl)ethan-1-one (4j, 6e).**<sup>10d</sup> 61.6 mg, 89.8 mg. Yield = 49%, 72%. Colorless oil.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.79 (d,  $J$  = 8.1 Hz, 2H), 7.20 (d,  $J$  = 8.1 Hz, 2H), 3.59 (t,  $J$  = 6.4 Hz, 2H), 2.71–2.67 (m, 2H), 2.49 (s, 3H), 2.43 (brs, 1H), 1.85–1.78 (m, 2H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  198.0, 147.8, 135.0, 128.6, 128.5, 61.9, 33.8, 32.0, 26.5 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{11}H_{15}O_2$ : 179.1067, found: 179.1069. FTIR (KBr, neat):  $\nu$  3438, 1679  $cm^{-1}$ .

**1-(4-Cyclohexylphenyl)ethan-1-one (4k).**<sup>10d</sup> 65.3 mg. Yield = 46%. Yellow solid.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.82–7.80 (m, 2H), 7.21 (d,  $J$  = 8.3 Hz, 2H), 2.49 (s, 3H), 1.79–1.75 (m, 4H), 1.70–1.66 (m, 1H), 1.40–1.14 (m, 6H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  197.8, 153.7, 134.9, 128.5, 127.0, 44.6, 34.0, 26.6, 26.5, 25.9 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{14}H_{19}O$ : 203.1430, found: 203.1436. FTIR (KBr, neat):  $\nu$  1671  $cm^{-1}$ .

**1,1'-(Ethane-1,2-diylbis(4,1-phenylene))bis(ethan-1-one) (6h).**<sup>17</sup> 151.2 mg. Yield = 81%. White solid.  $^1H$  NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.75 (d,  $J$  = 8.2 Hz, 4H), 7.11 (d,  $J$  = 8.2 Hz, 4H), 2.88 (s, 4H), 2.45 (s, 6H) ppm.  $^{13}C\{^1H\}$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  197.6, 146.5, 135.0, 128.5, 128.3, 37.0, 26.3 ppm. HRMS (ESI,  $m/z$ ):  $[M + H]^+$ , calcd. for  $C_{18}H_{19}O_2$ : 267.1380, found: 267.1385. FTIR (KBr, neat):  $\nu$  1679  $cm^{-1}$ .

## ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.9b00204.

$^1H$  and  $^{13}C$  NMR spectra of products (PDF)

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### Notes

The authors declare no competing financial interest.

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