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Divergent Synthesis of Benzene Derivatives: Brønsted Acid Catalyzed and Iodine-Promoted Tandem Cyclization of 5,2-Enyn-1-ones

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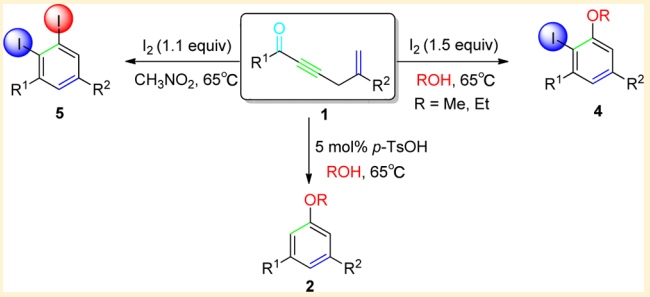
Supporting Information

ABSTRACT: Highly substituted benzene derivatives, including alkoxy-, iodoalkoxy-, and diiodo-substituted benzenes, can be selectively synthesized via Brønsted acid catalyzed and iodine-promoted tandem carbocyclization respectively. This reaction involved a direct process for C−C bond formation from 5,2-enyn-1-ones, and different reaction systems (Brønsted acids/electrophiles with solvents) afforded different substituted benzenes. Furthermore, the halogenated moiety and alkoxy group can be readily introduced into the benzene in a position which has not been easily obtained previously.

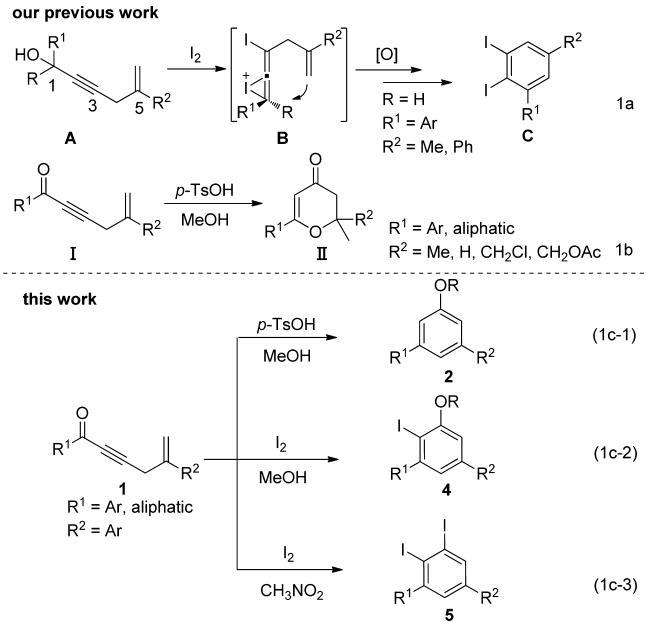


INTRODUCTION

The development of novel methods for the annulation of highly substituted benzene derivatives is very important in organic chemistry, because such substituted aromatic compounds are essential intermediates/substrates for organic synthesis.[1] They are also important structural units found in organic materials, such as optical and conductive materials. Traditionally, substituted benzenes are synthesized from benzene directly through various functionalization reactions.[2] However, the activation or deactivation of the benzene ring in the functional substitution may be correlated with the electron-donating or electron-withdrawing influence of the substituents, during which the selectivity is a problem, especially in introducing one group into the benzene in a special position. Moreover, benzene derivatives have also been synthesized by cyclotrimerization of alkynes with transition-metal catalysts, but one of the major problems with these reaction systems is the difficulty of regioselective intermolecular cyclotrimerization with unsymmetrical alkynes, which generally give a mixture of the multisubstituted benzene derivatives.[3] Thus, an ideal solution to construct benzenes directly from a suitably designed nonaromatic system is still of current demand. Previously, we have shown that an iodine-promoted carbocyclization of hydroxylated enynes can serve this purpose (Scheme 1a).[4a] However, this reaction was completed in two steps and involved the use of an oxidant. In order to remove these shortcomings and have a more efficient benzene-forming reaction, we designed 5,2-enyn-1-ones as precursors for cyclization.

Recently, our group has reported Brønsted acid catalyzed cycloisomerizations of 5,2-enyn-1-ones **I** with R^2 (Me, H, CH_2Cl, CH_2OAc) for the regioselective synthesis of a new type of dihydropyranones **II** (Scheme 1b).[4b] To further develop this type of strategy, other structural differences of the substrate need to be examined. We were convinced that Brønsted acids would activate the carbonyl group of 5,2-enyn-1-ones **1**, which favors Michael addition.[4b,5] Moreover, iodine could also induce electrophilic carbocyclization[6] of 5,2-enyn-1-ones **1**, in which the key step might be the attack of unactivated olefins on allenes promoted by the iodonium ion.[4a] Herein, we report a successful realization of Brønsted acid catalyzed and iodine-

Scheme 1. Design of Proposed Cyclization for the Synthesis of Benzene Derivatives



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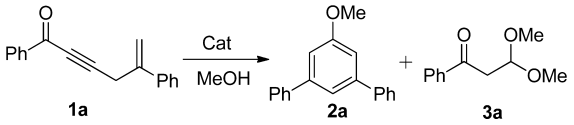
induced selective synthesis of highly substituted benzene derivatives from the 5,2-enyn-1-ones **1** (Scheme 1c). This chemistry offers a good method for the synthesis of a broad range of alkoxy-, iodoalkoxy-, and diiodo-substituted benzenes, which are of synthetic importance in both academia and industry.

RESULTS AND DISCUSSION

Initially, we attempted to extend the scope of our previously reported reaction of synthesizing dihydropyranone **II**[4b] by employing 1,5-diphenylhex-5-en-2-yn-1-one (**1a**) and *p*-TsOH (10 mol %) in methanol (Scheme 1b). Unexpectedly, the dihydropyranone product was not detected, but the benzene derivative 5′-methoxy-1,1′:3′,1″-terphenyl (**2a**; 60%) was obtained along with 30% of 3,3-dimethoxy-1-phenylpropan-1-one (**3a**),[7] which indicated that the cyclization process employed simple olefins as internal carbon nucleophiles to form the C−C bond (Table 1, entry 1). Then, the optimization

Table 1. Optimization of Cascade Cyclization for the Synthesis of 2a[a]



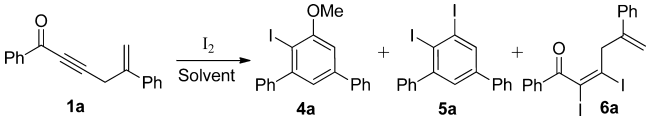
				yield (%)	
entry	cat. (amt (mol %))	temp (°C)	time (h)	**2a**	**3a**
1	*p*-TsOH (10)	75	12	60	34
2	TfOH (10)	75	12	55	38
3	TFA (10)	75	12	28[b]	15
4	$HAuCl_4{\cdot}4H_2O$	75	2	51	41
5	$Sc(OTf)_3$	75	6	50	36
6	$Bi(OTf)_3$	75	6	47	39
7	*p*-TsOH (5)	75	12	74	
8	*p*-TsOH (2)	75	12	70	
9	*p*-TsOH (5)	85	7	63	
10	***p*-TsOH (5)**	**65**	**12**	**78**	
11	*p*-TsOH (5)	55	12	72	

[a]Reaction conditions: **1a** (0.2 mmol) and MeOH (3.0 mL) in the presence of Brønsted or Lewis acids. [b]50% of **1a** was recovered.

studies of this novel cascade reaction were performed by using **1a** with different Brønsted acids, as shown in Table 1. Of these, *p*-TsOH proved to be the most efficient catalyst. A variety of Lewis acids such as $HAuCl_4{\cdot}4H_2O$, $Sc(OTf)_3$, and $Bi(OTf)_3$ were also screened; however, no superior yield of **2a** was obtained (Table 1, entries 4−6). When the *p*-TsOH loading was decreased to 5 mol %, the yield of **2a** was increased to 74% and **3a** was also not generated (Table 1, entries 7 and 8). When we decreased the temperature to 65 °C, **2a** was isolated in 78% yield after 12 h (Table 1, entry 10). Thus, the use of *p*-TsOH (5 mol %) in methanol at 65 °C was considered to be optimal reaction conditions to form **2a**.

In the context of our ongoing efforts to construct C−X (X = C, N, O) bonds by electrophilic cyclization of alkynes with nucleophiles,[8] we envisioned that this type of 5,2-enyn-1-ones **1** could realize this purpose for the construction of halogenated benzene derivatives. When we treated **1a** with molecular iodine (2.0 equiv) in CH_2Cl_2 at room temperature, to our delight, 10% of 4′,5′-diiodo-1,1′:3′,1″-terphenyl (**5a**) was obtained along with 50% of the addition product **6a** (Table 2, entry 1).

Table 2. Optimization of Electrophilic Carbocyclization for the Synthesis of 4a and 5a[a]



					yield (%)		
entry	solvent	amt of I_2 (equiv)	temp (°C)	time (h)	**4a**	**5a**	**6a**
1[b]	CH_2Cl_2	2	rt	10		12	50
2[c]	DCE	2	rt	10		10	48
3	CH_3NO_2	2	rt	7		25	65
4[d]	MeOH	2	rt	10	45	trace	20
5	MeOH	2	65	2	62	trace	
6	MeOH	3	65	1.5	56	trace	
7	**MeOH**	**1.5**	**65**	**2**	**70**		
8	MeOH	1.2	65	2	54		
9	MeOH	1.5	75	1.5	55		
10	MeOH	1.5	55	3	63		
11	CH_3NO_2	1.5	65	10		66	trace
12	**CH_3NO_2**	**1.1**	**65**	**10**		**70**	**trace**
13	CH_3NO_2	1.0	65	10		67	trace

[a]Reaction conditions: **1a** (0.2 mmol) and solvent (3.0 mL) in the presence of I_2. [b]30% of **1a** was recovered. [c]39% of **1a** was recovered. [d]25% of **1a** was recovered.

Changing the solvent from CH_2Cl_2 to DCE or CH_3NO_2 slightly influenced this transformation (Table 2, entries 2 and 3). Delightfully, using methanol as a solvent gave 45% of 4′-iodo-5′-methoxy-1,1′:3′,1″-terphenyl (**4a**) and a trace amount of **5a** (Table 2, entry 4). Increasing the temperature to 65 °C and decreasing the amount of I_2 to 1.5 equiv improved the yield of **4a** to 70% (Table 2, entries 5−10). The conditions for selective synthesis of **5a** were also extensively screened (Table 2, entries 11−13). Finally, we found that the optimized reaction conditions for **4a** were 1.5 equiv of I_2 in methanol at 65 °C (Table 2, entry 7), whereas the standard conditions for **5a** were selected as I_2 (1.1 equiv) in CH_3NO_2 at 65 °C (Table 2, entry 12).

Under the optimized conditions, various representative 5,2-enyn-1-ones **1a−q** were then subjected to the optimized conditions for the synthesis of methoxybenzene derivatives **2**, as depicted in Table 3. The reaction works well with aromatic R^1 and R^2 groups. Electron-rich aryl groups showed better results than those with an electron-withdrawing group in this carbocyclization (**2b−d** vs **2f,g**, **2m** vs **2n**, and **2o** vs **2p**). Actually, R^2 with an electron-donating group would influence the stability of the intermediate **M**, as delineated in Scheme 5. The steric effect was also investigated in this reaction: substrates such as **1e,j,q** with a more hindered group gave the corresponding products in lower yields, indicating that the steric effect plays a major role in this transformation. Substrates with a heteroaromatic moiety or an aliphatic group afforded the desired products **2h,i,l** in yields of 49%, 41%, and 39%, respectively. When a substrate with styrene R^1 group and two olefin groups was subjected to the optimal reaction conditions, it was found that the corresponding **2k** was not generated. This might be due to the fact that the styrene nucleus is not stable in this reaction system.

Next, to examine the scope of the electrophilic carbocyclization, we also investigated a wide range of 5,2-enyn-1-ones **1a−q** with different aromatic R^1 and R^2 groups in the presence of I_2

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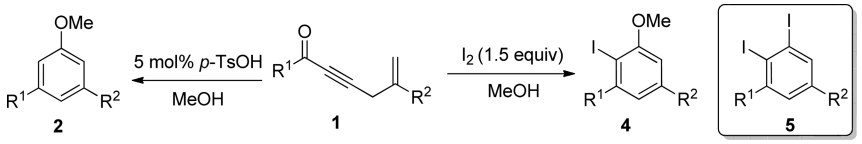
Table 3. Synthesis of Methoxy- and Iodomethoxy-Substituted Benzenes 2 and 4 from 5,2-Enyn-1-ones 1[a]



entry	substrate (R^1, R^2)	yield (%) 2	yield (%) 4
1	Ph, Ph	78 (**2a**)	70 (**4a**)
2	*p*-MeC_6H_4, Ph	70 (**2b**)	63 (**4b**)
3	*p*-$OMeC_6H_4$, Ph	86 (**2c**)	72 (**4c**)
4	*m*-$OMeC_6H_4$, Ph	60 (**2d**)	55 (**4d**)
5	2,5-dimethoxy, Ph	20 (**2e**)	trace[b] (**4e**)
6	*p*-ClC_6H_4, Ph	66 (**2f**)	70 (**4f**)
7	*m*-ClC_6H_4, Ph	60 (**2g**)	65 (**4g**)
8	2-thienyl, Ph	49 (**2h**)	35[c] (**4h**)
9	2-furyl, Ph	41 (**2i**)	45 (**4i**)
10	piperonyl, Ph	40 (**2j**)	58 (**4j**)
11	styryl, Ph	–[d] (**2k**)	62 (**4k**)
12	*n*-propyl, Ph	39 (**2l**)	51 (**4l**)
13	Ph, *p*-MeC_6H_4	78 (**2m**)	47[e] (**4m**)
14	Ph, *p*-ClC_6H_4	76 (**2n**)	35[f] (**4n**)
15	*p*-$OMeC_6H_4$, *p*-MeC_6H_4	81 (**2o**)	45[g] (**4o**)
16	*p*-$OMeC_6H_4$, *p*-ClC_6H_4	62 (**2p**)	57 (**4p**)
17	1-naphthyl, Ph	trace (**2q**)	trace (**4q**)

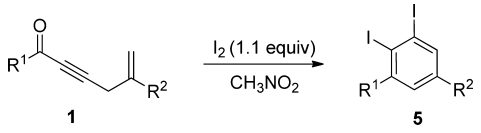
[a]Conditions for **2**: the reaction was carried out by using **1** (0.2 mmol) and 5 mol % of *p*-TsOH in methanol (3 mL) at 65 °C. Conditions for **4**: the reaction was carried out by using **1** (0.2 mmol) and 1.5 equiv of I_2 in methanol (3 mL) at 65 °C. [b]20% of **5e** was isolated. [c]20% of **5h** was isolated. [d]Decomposed. [e]12% of **5h** was isolated. [f]A trace amount of **5n** was observed. [g]20% of **5o** was isolated.

in methanol. It was found that these substrates (except **1e**,**q**) were effectively converted into the corresponding iodomethoxybenzene derivatives **4a**–**p** in moderate to good yield, as depicted in Table 3. The reaction tolerates the presence of different electron-rich and electron-withdrawing aryl groups. The steric effect was also tolerated in this reaction. Unfortunately, with a substrate such as **1e** with a 2,5-dimethoxy aryl group, just a trace amount of the desired product **4e** was observed, while the diiodo-substituted benzene **5e** was obtained in 20% yield. This might be due to the fact that the intermediate cation **D** was more easily captured by iodide anion than methanol in this case (Scheme 5). Other substrates such as **1h**,**m**–**o**, in addition to the desired iodomethoxy-substituted benzenes **4h**,**m**–**o** were obtained in moderate yield; diiodo-substituted benzenes **5h**,**m**–**o** were also observed. Interestingly, in comparison with *p*-TsOH-catalyzed cyclization for the synthesis of **2k**, substrate **1k** with a styrene R^1 group has little effect on this carbocyclization and **4k** was isolated in 62% yield.

Furthermore, we also investigated the selective synthesis of diiodobenzene derivatives **5** via iodine-promoted electrophilic carbocyclization, as depicted in Table 4. Thus, a tandem carbon–carbon bond formation of 5,2-enyn-1-one derivatives proceeded smoothly to afford the corresponding products in moderate yields. The reaction works well with aromatic R groups. Fortunately, when 5,2-enyn-1-one **1k** with two olefin groups was subjected to the above conditions, it was found that the styrene group was selectively retained in this reaction and a good yield of the corresponding **5k** was obtained. Interestingly, it was found that for substrate **1q**, just trace amounts of **2q** and **4q** can be observed, while **5q** can be isolated in a yield of 43%.

Knowing the importance of polycyclic derivatives in organic materials,[9] which are used for the preparation of many optical

Table 4. Selective Synthesis of Diiodobenzene Derivatives 5[a]



entry	substrate (R^1, R^2)	time (h)	yield (%)
1	Ph, Ph	10	70 (**5a**)
2	*p*-MeC_6H_4, Ph	12	52 (**5b**)
3	*p*-ClC_6H_4, Ph	12	63 (**5f**)
4	piperonyl, Ph	10	55 (**5j**)
5	styryl, Ph	7	74 (**5k**)
6	Ph, *p*-MeC_6H_4	10	46 (**5m**)
7	*p*-$OMeC_6H_4$, *p*-MeC_6H_4	10	44 (**5o**)
8	1-naphthyl, Ph	12	43 (**5q**)

[a]The reaction was carried out by using **1** (0.2 mmol) and 1.1 equiv of I_2 in CH_3NO_2 (3 mL) at 65 °C.

and conductive materials, we also prepared the symmetrical 5,2-enyn-1-one substrate **1r**, and it was found that by increasing the amount of corresponding catalyst loading, the expected products **2r** and **4r** were obtained in yields of 30% and 27%, respectively (Scheme 2).

Furthermore, to exploit the synthetic utility of this reaction, we also investigated the influence of different alcohols (Scheme 3). It was found that **1a** in the presence of 5 mol % *p*-TsOH with ethanol as solvent gave the corresponding **2aa** in low yield (20%), whereas phenol failed to give the product, which might be due to the more hindered nature of the nucleophile in the nucleophilic attack step. The role of the alcohol in electrophilic carbocyclization was also investigated. When the reaction was performed in ethanol, **4aa** was obtained in a yield of 57%. Not

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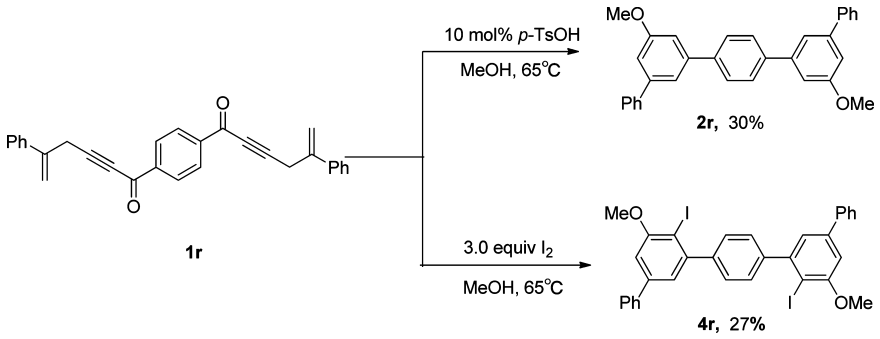
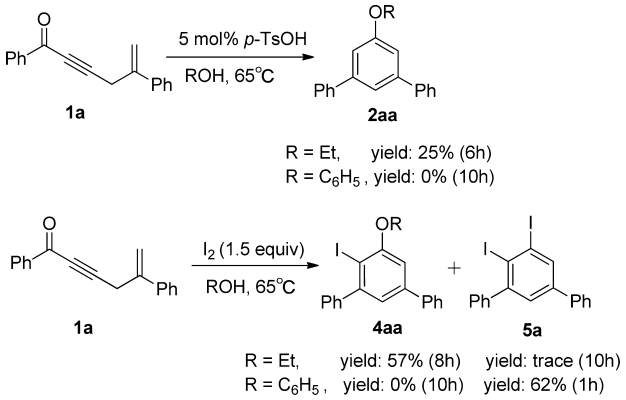
Scheme 2. Synthesis of Polycyclic Derivatives 2r and 4r



Scheme 3. Influence of Different Alcohols on the Outcome of Reaction

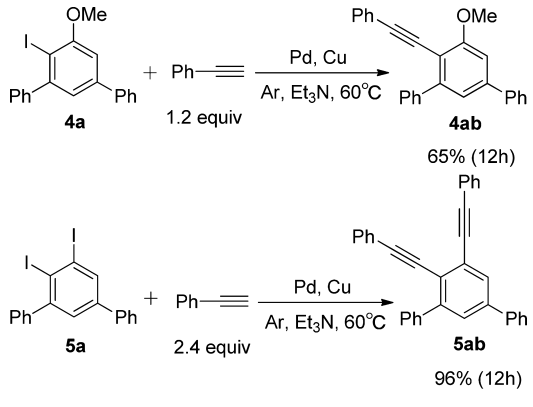


surprisingly, using phenol as solvent, the 1-iodo-2-oxybenzene derivative was not afforded but **5a** was generated in 62% yield.

A standard feature of this process is the fact that the iodo-substituted benzenes produced by carbocyclization can be further elaborated by using various palladium-catalyzed processes. For example, the Sonagashira coupling[10] of **4a** and **5a** afforded the corresponding products **4ab** and **5ab** in excellent yields (Scheme 4).

On the basis of the above observations and the isolation of intermediate,[11] a possible reaction mechanism is proposed as shown in Scheme 5. Initial interaction of the proton generated from iodine and protic solvents (or from the Brønsted acid) with the carbonyl oxygen atom of **1** gives complex **A**. Alcohol (or iodide) as nucleophiles attacks the carbon−carbon triple bond to form **B** (or **F** and **J**).[12] Attack of the electrophile (iodine cation) onto the allene **B** (or **F**) affords **C** (or **G**). The activation of the carbonyl precedes the intramolecular nucleophlic attack by the alkene moiety, thereby generating a newly formed carbon−carbon bond (**D** or **H**),[13] which undergoes deprotonation and dehydration to give product **4** (or **5**). The mechanism for **2** was also proposed. **J** releases a proton; a subsequent keto−enol tautomerization would lead to the formation of intermediate **K** and regenerate the acid catalyst. Owing to the steric hindrance, **K** on heating undergoes subsequent convertion to **L** (allylic substrates with methyl as the R^2 group afforded a significant amount of lactone derivative, presumably through the competitive intramolecular nucleophilic addition of the oxygen of the carbonyl group to the alkene group position).[4b] Attack of the terminal olefin at the carbonyl carbon of **L** affords **M**, which undergoes deprotonation and dehydration to give product **2**.

Scheme 4. Palladium-Catalyzed Sonogashira Coupling Reaction

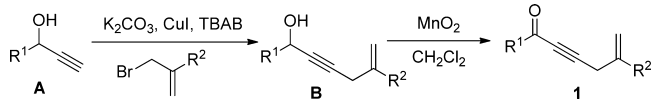


CONCLUSION

In summary, we have reported a direct and highly selective protocol for preparing different alkoxy-, iodoalkoxy-, and diiodobenzene derivatives from 5,2-enyn-1-ones in the presence of Brønsted acid or molecular iodine. The reaction involves an efficient process for C−C bond formation, and the product nature is tunable by the steric hindrance of the nucleophile and the substituted groups of the starting materials. The resulting iodobenzene derivatives can be further functionalized by using known organopalladium chemistry.

EXPERIMENTAL SECTION

General Procedure A: Synthesis of 5,2-Enyn-1-ones 1.[4] For the synthesis of **1a**: to a stirred solution of 1-phenyl-2-propyn-1-ol (**A**;



10 mmol) in dry DMF (10 mL) under argon were sequentially added K_2CO_3 (1.93 g, 14 mmol), tetrabutylammonium bromide (483 mg, 1.5 mmol), and copper(I) iodide (96 mg, 0.5 mmol) at room temperature. After 15 min, (3-bromoprop-1-en-2-yl)benzene (15 mmol) was added. The reaction mixture was stirred for 24 h. Then it was poured into water and extracted with ether. The combined organic layers were washed with a saturated aqueous sodium chloride solution, dried over Na_2SO_4, and filtered, and the solvents were removed under reduced pressure. The residue was purified by flash column chromatography (silica gel, petroleum ether/ethyl acetate 10/1) to give the corresponding propargylic alcohol (80%).

MnO_2 (75 mmol, 15 equiv) was added to a solution of 1,5-diphenylhex-5-en-2-yn-1-ol (5 mmol) in CH_2Cl_2 (10 mL) at room

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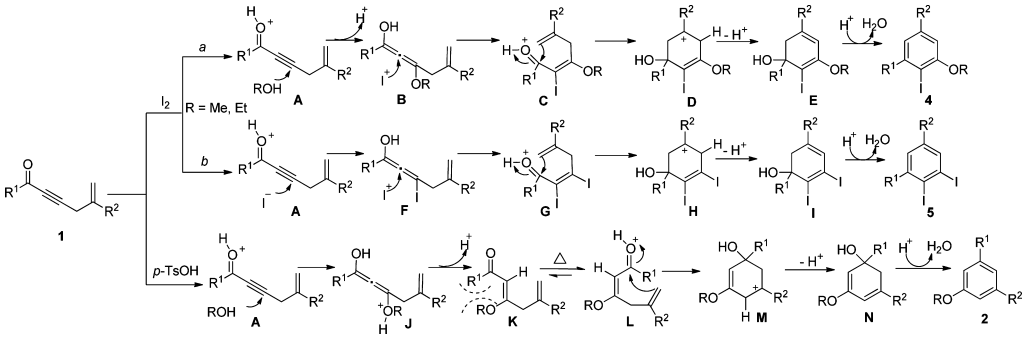
Scheme 5. Proposed Mechanisms



temperature. The resulting mixture was stirred overnight. Then the solid was filtered and the solvents were removed under reduced pressure. The residue was purified by flash column chromatography (silica gel, petroleum ether/ethyl acetate 20/1) to give 5,2-enyn-1-one **1a** (75%).

General Procedure B: Synthesis of Methoxy-Substituted Benzenes 2. To a solution of 5,2-enyn-1-one **1** (0.20 mmol) in MeOH (3.0 mL) was added 5 mol % of *p*-TsOH. The resulting mixture was stirred at 65 °C. When the reaction was considered complete as determined by TLC analysis, the reaction mixture was diluted with ethyl ether (40 mL), washed with water and saturated brine, dried over Na_2SO_4, and evaporated under reduced pressure. The residue was purified by chromatography on silica gel to afford the corresponding products **2**.

General Procedure C: Synthesis of Iodomethoxy and Diiodobenzene Derivatives 4 and 5. To a solution of 5,2-enyn-1-one **1** (0.20 mmol) in MeOH (3.0 mL) was added 1.5 equiv of I_2. The resulting mixture was stirred at 65 °C. When the reaction was considered complete as determined by TLC analysis, the reaction mixture was quenched with a saturated aqueous solution of $Na_2S_2O_3$, diluted with ethyl ether (40 mL), washed with water and saturated brine, dried over Na_2SO_4, and evaporated under reduced pressure. The residue was purified by chromatography on silica gel to afford products **4** and **5**.

General Procedure D: Synthesis of Diiodo-Substituted Benzenes 5. To a mixture of 5,2-enyn-1-one **1** in CH_3NO_2 (3.0 mL) was added 1.1 equiv of I_2. The resulting mixture was then stirred at 65 °C. When the reaction was considered complete as determined by TLC, the reaction mixture was quenched with a saturated aqueous solution of $Na_2S_2O_3$ and extracted with ethyl acetate. The combined organic extracts were washed with water and saturated brine, dried over Na_2SO_4, and evaporated under reduced pressure. The residue was purified by chromatography on silica gel to afford products **5**.

Characterization Data of 2a–r. *5′-Methoxy-1,1′:3′,1″-terphenyl (**2a**):* yield 78%; light yellow solid; mp 92–94 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (d, J = 7.2 Hz, 4H), 7.46 (t, J = 8.0 Hz, 4H), 7.40–7.35 (m, 3H), 7.14 (d, J = 1.2 Hz, 2H), 3.92 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.3, 143.2, 141.1, 128.8, 127.5, 127.3, 118.9, 111.8, 55.5; IR (neat, cm^{-1}): 2923, 1594, 1495, 1458, 1409, 1382, 1205, 1071, 1023, 859, 759, 696; HRMS (ESI) calcd for $C_{19}H_{16}O$ ([M + H]$^+$) 261.1274, found 261.1274.

*5′-Methoxy-4-methyl-1,1′:3′,1″-terphenyl (**2b**):* yield 70%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (d, J = 8.0 Hz, 2H), 7.54 (d, J = 7.6 Hz, 2H), 7.45 (t, J = 7.6 Hz, 2H), 7.39–7.34 (m, 2H), 7.25(d, J = 4.0 Hz, 2H), 7.09 (s, 2H), 3.91 (s, 3H), 2.40 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.3 143.1, 143.1, 141.2, 138.2, 137.4, 129.5, 128.7, 127.5, 127.3, 127.1, 118.7, 111.6, 111.5, 55.4, 21.1; IR (neat, cm^{-1}): 2922, 2852, 1594, 1574, 1515, 1460, 1420, 1382, 1205, 1071, 1023, 815, 761, 698; HRMS (ESI) calcd for $C_{20}H_{18}O$ ([M + H]$^+$) 275.1430, found 275.1433.

*4,5′-Dimethoxy-1,1′:3′,1″-terphenyl (**2c**):* yield 86%; yellow solid; mp 62–64 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (d, J = 7.6 Hz, 2H) 7.59–7.55 (m, 2H), 7.45 (t, 8.0 Hz, 2H), 7.38–7.34 (m, 2H), 7.07 (d, J = 1.2 Hz, 2H), 6.98 (d, J = 8.8 Hz, 2H), 3.90 (s, 3H), 3.85 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.3, 159.3, 143.1, 142.7, 141.2, 133.6, 128.7, 128.3, 127.5, 127.3, 118.5, 114.2, 111.4, 111.1, 55.4, 55.3; IR (neat, cm^{-1}): 2924, 2853, 1594, 1576, 1514, 1460, 1423, 1382, 1252, 1206, 1176, 1027, 887.6, 828.6, 762, 700, 642; HRMS (ESI) calcd for $C_{20}H_{18}O_2$ ([M + H]$^+$) 291.1380, found 291.1393.

*3,5′-Dimethoxy-1,1′:3′,1″-terphenyl (**2d**):* yield 60%; light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56–7.54 (m, 2H), 7.36 (t, J = 7.6 Hz, 2H), 7.31–7.28 (m, 3H), 7.15–7.13 (m, 1H), 7.08 (t, J = 2.0 Hz, 1H), 7.03 (s, 2H), 6.83 (dd, J = 8.4 Hz, 2.4 Hz, 1H), 3.82 (s, 3H), 3.78(s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.24, 159.9, 143.1, 143.0, 142.6, 141.1, 129.8, 128.8, 127.5, 127.3, 119.8, 118.9, 113.0, 112.9, 111.9, 111.8, 55,4, 55.4, 55.3, 55.3; IR (neat, cm^{-1}): 2920, 2851, 1580, 1542, 1494, 1462, 1403, 1384, 1212, 1171, 1071, 1042, 853, 762, 698; HRMS (ESI) calcd for $C_{20}H_{18}O_2$ ([M + H]$^+$) 291.1380, found 291.1390.

*2,5,5′-Trimethoxy-1,1′:3′,1″-terphenyl (**2e**):* yield 20%; light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63–7.61 (m, 2H), 7.44 (t, J = 7.6 Hz, 2H), 7.37–7.33 (m, 2H), 7.11–7.09 (m, 2H), 6.97–6.92 (m, 2H), 6.87 (dd, J = 9.2 Hz, 3.2 Hz, 1H), 3.89 (s, 3H), 3.81 (s, 3H), 3.78 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 159.6, 153.7, 150.8, 142.4, 141.2, 140.1, 131.5, 128.7, 127.4, 127.3, 121.1, 116.7, 114.1, 113.4, 112.7, 111.8, 56.4, 55.8, 55.4; IR (neat, cm^{-1}): 2922, 2852, 1591, 1541, 1499, 1461, 1384, 1219, 1045, 1028, 859, 803, 763, 730, 699; HRMS (ESI) calcd for $C_{21}H_{20}O_3$ ([M + H]$^+$) 321.1485, found 321.1485.

*4-Chloro-5′-methoxy-1,1′:3′,1″-terphenyl (**2f**):* yield 66%; orange oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64–7.61 (m, 2H), 7.56 (d, 8.8 Hz, 2H), 7.47–7.35 (m, 6H), 7.12 (t, J = 1.6 Hz, 1H), 7.60 (t, J = 2.0 Hz, 1H), 3.91 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.4, 143.4, 141.9, 141.0 139.5, 133.6, 128.9, 128.8, 128.5, 127.7, 127.3, 118.7, 112.0, 111.6, 55.5; IR (neat, cm^{-1}): 2923, 2852, 1594, 1496, 1461, 1421, 1388, 1207, 1175, 1091, 1073, 1017, 824, 762, 699; HRMS (ESI) calcd for $C_{19}H_{15}ClO$ ([M + H]$^+$) 295.0884, found 295.0887.

*3-Chloro-5′-methoxy-1,1′:3′,1″-terphenyl (**2g**):* yield 60%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, J = 7.6 Hz, 3H), 7.51–7.44 (m, 3H), 7.39–7.32 (m, 4H), 7.13 (t, J = 1.6 Hz, 1H), 7.06 (t, J = 2.0 Hz, 1H) 3.91 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.4, 143.4, 142.9, 141.7, 140.9, 134.6, 130.0, 128.8, 127.7, 127.5, 127.4, 127.3, 125.4, 118.8, 112.3, 111.6, 55.5; IR (neat, cm^{-1}): 2922, 2851, 1593, 1570, 1497, 1460, 1422, 1393, 1207, 1175, 1074, 1040, 848, 784, 762, 719, 696; HRMS (ESI) calcd for $C_{19}H_{15}ClO$ ([M + H]$^+$) 295.0884, found 295.0885.

*2-(5-Methoxy-[1,1′-biphenyl]-3-yl)thiophene (**2h**):* yield 50%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (d, J = 1.2 Hz, 2H), 7.61–7.35 (m, 5H), 7.29 (dd, J = 5.2 Hz, 0.8 Hz, 1H), 7.13 (t, J = 2.0 Hz, 1H), 7.09 (dd, J = 4.8 Hz, 3.6 Hz, 1H), 7.05 (t, J = 2.0 Hz, 1H) 3.91 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.3, 144.2, 143.4, 140.9, 136.0, 128.8, 128.8, 128.0, 127.7, 127.2, 127.2, 125.0, 123.5, 117.8, 112.1, 110.5, 55.5; IR (neat, cm^{-1}): 2922, 2854, 1563, 1455, 1262, 1095, 1024, 873, 806, 760, 698; HRMS (ESI) calcd for $C_{17}H_{14}OS$ ([M + H]$^+$) 267.0838, found 267.0841.

*2-(5-Methoxy-[1,1′-biphenyl]-3-yl)furan (**2i**):* yield 40%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, J = 5.2 Hz, 2H), 7.5–7.43

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(m, 4H), 7.39−7.35 (m, 1H), 7.21−7.20 (m, 1H), 7.03 (dd, J = 2.4 Hz, 1.6 Hz, 1H), 6.70−6.70 (m, 1H), 6.49 (q, J = 1.6 Hz, 1H), 3.91 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.3, 153.8, 143.2, 142.2, 140.9, 132.5, 128.7, 127.6, 127.2, 115.5, 112.2, 111.7, 108.0, 105.5, 55.5; IR (neat, cm^{-1}): 2923, 2853, 1597, 1573, 1496, 1460, 1381, 1208, 1155, 1069, 1022, 869, 802, 761, 697; HRMS (ESI) calcd for $C_{17}H_{14}O_2$ ([M + H]$^+$) 251.1067, found 251.1066.

5-(5Methoxy-[1,1′-biphenyl]-3-yl)benzo[d][1,3]dioxole ***(2j):*** yield 40%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, J = 7.2 Hz, 2H), 7.44 (t, J = 7.6 Hz, 2H), 7.36 (t, J = 7.2 Hz, 1H), 7.32 (s, 1H), 7.11−7.07 (m, 3H), 7.03 (d, J = 1.6 Hz, 1H), 6.89−6.87 (m, 1H), 5.99 (s, 2H), 3.90 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.3, 148.1, 147.3, 143.1, 142.8, 141.1, 135.5, 128.7, 127.5, 127.3, 120.8, 118.6, 111.5, 111.4, 108.5, 107.8, 101.2, 55.4, 29.7; IR (neat, cm^{-1}): 2919, 2851, 2361, 1624, 1580, 1541, 1500, 1419, 1383, 1067, 1040, 799, 763, 668; HRMS (ESI) calcd for $C_{20}H_{16}O_3$ ([M + H]$^+$) 305.1172, found 305.1176.

3-Methoxy-5-propyl-1,1′-biphenyl ***(2l):*** yield 39%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52−7.50 (m, 2H), 7.35 (t, J = 8.0 Hz, 2H), 7.26 (t, J = 7.2 Hz, 1H), 6.93 (s, 1H), 6.87 (s, 1H), 6.66 (s, 1H), 3.78 (s, 3H), 2.55 (t, J = 7.6 Hz, 2H), 1.66−1.57 (m, 2H), 0.90 (t, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 159.9, 144.7, 142.5, 141.4, 128.7, 127.3, 127.2, 120.1, 113.1, 110.0, 55.3, 38.3, 24.5, 13.9; IR (neat, cm^{-1}): 2923, 2867, 1596, 1460, 1422, 1382, 1215, 1157, 1057, 847, 762, 699; HRMS (ESI) calcd for $C_{16}H_{18}O$ ([M + H]$^+$) 227.1430, found 227.1430.

5′-Methoxy-4-methyl-1,1′:3′,1″-terphenyl ***(2m):*** yield 78%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 (d, J = 7.6 Hz, 2H), 7.45 (d, J = 8.0 Hz, 2H), 7.35 (t, J = 7.6 Hz, 2H), 7.30−7.25 (m, 2H), 7.16 (d, J = 7.6 Hz, 2H), 7.01 (s, 2H), 3.81 (s, 3H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.3, 143.1, 143.1, 141.2, 138.2, 137.3, 129.5, 128.7, 127.5, 127.3, 127.1, 118.7, 111.6, 111.5, 55.4, 21.1; IR (neat, cm^{-1}): 2921, 1595, 1515, 1457, 1420, 1388, 1206, 1174, 1072, 1023, 869, 815, 762, 699; HRMS (ESI) calcd for $C_{20}H_{18}O$ ([M + H]$^+$) 275.1430, found 275.1432.

4-Chloro-5′-methoxy-1,1′:3′,1″-terphenyl ***(2n):*** yield 78%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, J = 7.6 Hz, 2H), 7.56 (d, J = 8.4 Hz, 2H), 7.47−7.34 (m, 6H), 7.11 (s, 1H), 7.06 (d, J = 1.6 Hz, 1H), 3.91 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.4, 143.4, 141.9, 141.0, 139.6, 133.7, 128.9, 128.8, 128.5, 127.7, 127.3, 118.7, 112.0, 111.7, 55.5; IR (neat, cm^{-1}): 2924, 2853, 1596, 1496, 1460, 1383, 1207, 1098, 1071, 1021, 824, 761, 699; HRMS (ESI) calcd for $C_{19}H_{15}ClO$ ([M + H]$^+$) 295.0884, found 295.0884.

4,5′-Dimethoxy-4″-methyl-1,1′:3′,1″-terphenyl ***(2o):*** yield 81%; white solid; mp 97−99 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (dd, J = 14.0 Hz, 8.0 Hz, 4H), 7.25 (s, 1H), 7.16 (d, J = 7.6 Hz, 2H), 6.96 (s, 2H), 6.89 (d, J = 8.4 Hz, 2H), 3.80 (s, 3H), 3.74 (s, 3H), 2.30 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.3, 159.3, 143.0, 142.7, 138.3, 137.3, 133.7, 129.4, 128.3, 127.1, 118.3, 114.2, 111.1, 111.0, 55.4, 55.4, 55.3, 55.3, 21.1, 21.1; IR (neat, cm^{-1}): 2922, 2836, 1593, 1511, 1451, 1389, 1248, 1204, 1174, 1070, 1027, 812, 697; HRMS (ESI) calcd for $C_{21}H_{20}O$ ([M + H]$^+$) 305.1536, found 305.1540.

4-Chloro-4″,5′-dimethoxy-1,1′:3′,1″-terphenyl ***(2p):*** yield 62%; white solid; mp 99−101 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (dd, J = 8.8 Hz, 2.0 Hz, 4H), 7.34 (d, J = 8.8 Hz, 2H), 7.23 (d, J = 1.2 Hz, 1H), 7.00 (t, J = 2.0 Hz, 1H), 6.95−6.90 (m, 3H), 3.83 (s, 3H), 3.78 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.4, 159.4, 142.9, 141.8, 139.6, 133.6, 133.4, 128.9, 128.5, 128.3, 118.3, 114.2, 111.6, 111.0, 55.4, 55.3; IR (neat, cm^{-1}): 2921, 2852, 1593, 1512, 1454, 1384, 1256, 1206, 1175, 1092, 1029, 821, 698; HRMS (ESI) calcd for $C_{20}H_{17}ClO_2$ ([M + H]$^+$) 325.0990, found 325.0994.

5′,5‴-Dimethoxy-1,1′:3′,1″:4″,1‴:3‴,1⁗-quinquephenyl ***(2r):*** yield 30%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (s, 4H), 7.67−7.65 (m, 4H), 7.49−7.45 (m, 6H), 7.40−7.36 (m, 2H), 7.17 (t, J = 2.0 Hz, 2H), 7.13 (t, J = 2.0 Hz, 2H), 3.94 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.4, 143.3, 142.6, 141.1, 140.3, 128.8, 127.7, 127.6, 127.3, 118.8, 111.9, 111.7, 55.5 IR (neat, cm^{-1}): 2922, 2853, 1593, 1461, 1383, 1207, 1070, 1024, 828, 762, 699; HRMS (ESI) calcd for $C_{32}H_{26}O$ ([M + H]$^+$) 443.2006, found 443.2010.

Characterization Data of 4a−r. *4′-Iodo-5′-methoxy-1,1′:3′,1″-terphenyl* ***(4a):*** yield 70%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62−7.60 (m, 2H), 7.46−7.35 (m, 8H), 7.17 (d, J = 2.0 Hz, 1H), 7.01 (d, J = 2.0 Hz, 1H), 4.00 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.6, 148.9, 144.5, 142.3, 140.2, 129.3, 128.9, 127.9, 127.8, 127.6, 127.1, 121.6, 108.3, 90.0, 56.7; IR (neat, cm^{-1}): 2924, 1579, 1561, 1492, 1455, 1389, 1065, 1022, 849, 762, 699, 566; HRMS (ESI) calcd for $C_{19}H_{15}IO$ ([M + H]$^+$) 387.0240, found 387.0243.

6′-Iodo-5′-methoxy-4-methyl-1,1′:3′,1″-terphenyl ***(4b):*** yield 63%; light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60−7.58(m, 2H), 7.44−7.40 (m, 2H), 7.37−7.33 (m, 1H), 7.28−7.22 (m, 4H), 7.15 (d, J = 2.0 Hz, 1H), 6.98 (d, J = 2.0 Hz, 1H), 3.98 (s, 3H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.6, 148.9, 142.3, 141.6, 140.2, 137.3, 129.2, 128.8, 128.6, 127.8, 127.1, 121.7, 108.2, 90.2, 56.7, 56.7, 21.3; IR (neat, cm^{-1}): 2922, 2851, 1558, 1513, 1497, 1458, 1430, 1390, 1228, 1139, 1037, 1015, 849, 818, 762, 698, 578; HRMS (ESI) calcd for $C_{20}H_{17}IO$ ([M + H]$^+$) 401.0397, found 401.0399.

6′-Iodo-4,5′-dimethoxy-1,1′:3′,1″-terphenyl ***(4c):*** yield 72%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64−7.59 (m, 2H), 7.43 (t, J = 7.6 Hz, 2H), 7.37 (d, J = 7.6 Hz, 1H), 7.34−7.30 (m, 2H), 7.16 (d, 2.0 Hz, 1H) 6.99−6.94 (m, 3H), 3.99 (s, 3H), 3.86 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 159.1, 158.6, 148.5, 142.3, 140.2, 137.0, 130.5, 128.9, 127.8, 127.1, 126.9, 121.8, 113.3, 113.2, 108.1, 90.6, 56.7, 55.3; IR (neat, cm^{-1}): 2930, 2834, 1608, 1557, 1511, 1462, 1430, 1389, 1245, 1140, 1032, 888, 830, 762, 697, 560; HRMS (ESI) calcd for $C_{20}H_{17}IO_2$ ([M + H]$^+$) 417.0346, found 417.0350.

6′-Iodo-3,5′-dimethoxy-1,1′:3′,1″-terphenyl ***(4d):*** yield 55%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60 (d, J = 6.2 Hz, 2H), 7.43 (t, J = 8.0 Hz, 2H), 7.35 (q, J = 7.6 Hz, 2H), 7.17 (d, J = 1.6 Hz, 1H), 7.00 (d, J = 1.6 Hz, 1H), 6.97−6.92 (m, 3H), 3.99 (s, 3H), 3.84 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 159.0, 158.6, 148.7, 145.7, 142.3, 140.1, 128.9, 128.9, 127.8, 127.1, 121.5, 114.9, 113.3, 108.3, 89.8, 56.7, 56.7, 55.3, 55.3; IR (neat, cm^{-1}): 2921, 2850, 1582, 1560, 1489, 1458, 1427, 1387, 1215, 1031, 856, 762, 699, 588; HRMS (ESI) calcd for $C_{20}H_{17}IO_2$ ([M + H]$^+$) 417.0346, found 417.0354.

4-Chloro-6′-iodo-5′-methoxy-1,1′:3′,1″-terphenyl ***(4f):*** yield 70%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61−7.58 (m, 2H), 7.46−7.38 (m, 5H), 7.31 (d, J = 8.8 Hz, 2H), 7.12 (d, J = 2.0 Hz, 1H), 7.01 (d, J = 2.0 Hz, 1H), 4.00 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.7, 147.7, 142.8, 142.5, 140.0, 133.7, 130.7, 128.9, 128.2, 128.0, 127.1, 121.5, 108.6, 89.8, 56.7; IR (neat, cm^{-1}): 2920, 2850, 1579, 1557, 1491, 1459, 1430, 1385, 1228, 1089, 1014, 829, 762, 698; HRMS (ESI) calcd for $C_{19}H_{14}ClIO$ ([M + H]$^+$) 420.9851, found 420.9851.

3-Chloro-6′-iodo-5′-methoxy-1,1′:3′,1″-terphenyl ***(4g):*** yield 65%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61−7.59 (m, 2H), 7.44 (t, J = 7.6 Hz, 2H), 7.39−7.36 (m, 4H), 7.27−7.25 (m, 1H), 7.12 (d, J = 2.0 Hz, 1H), 7.01 (s, J = 2.0 Hz, 1H), 4.00 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.7, 147.4, 146.0, 142.6, 140.0, 133.7, 129.4, 129.2, 128.9, 128.0, 127.7, 127.7, 127.1, 121.4, 108.7, 89.6, 56.7; IR (neat, cm^{-1}): 2919, 2850, 1561, 1458, 1431, 1386, 1146, 1073, 1039, 853, 786, 762, 697; HRMS (ESI) calcd for $C_{19}H_{14}ClIO$ ([M + H]$^+$) 420.9851, found 420.9849.

2-(4-Iodo-5-methoxy-[1,1′-biphenyl]-3-yl)thiophene ***(4h):*** yield 35%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (d, J = 8.4 Hz, 2H), 7.36−7.32 (m, 2H), 7.29−7.25 (m, 2H), 7.20 (d, J = 2.0 Hz, 1H), 7.13−7.10 (m, 1H), 7.02−7.00 (m, 1H), 6.91 (s, 1H), 3.88 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.9, 145.2, 142.3, 141.6, 139.9, 128.9, 127.9, 127.8, 127.1, 126.7, 125.7, 122.9, 109.1, 91.3, 56.8; IR (neat, cm^{-1}): 2922, 2851, 1559, 1458, 1387, 1261, 1115, 1088, 1029, 851, 801, 760, 696; HRMS (ESI) calcd for $C_{17}H_{13}IOS$ ([M + H]$^+$) 392.9805, found 392.9812.

2-(4-Iodo-5-methoxy-[1,1′-biphenyl]-3-yl)furan ***(4i):*** yield 45%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63−7.60 (m, 2H), 7.54−7.49 (m, 1H), 7.48−7.43 (m, 3H), 7.39−7.20 (m, 1H) 7.07−6.98 (m, 2H), 6.54−6.48 (m, 1H), [3.98 (s), 3.90 (s), 3H]; ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.9, 153.9, 142.6, 142.2, 140.1, 137.6, 128.9, 128.7, 127.9, 127.2, 127.1, 121.2, 111.0, 110.2, 108.9, 86.9, 56.8; IR

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(neat, cm^{-1}): 2921, 2852, 1553, 1495, 1459, 1389, 1227, 1136, 1085, 1036, 878, 808, 761, 697, 593; HRMS (ESI) calcd for $C_{17}H_{13}IO_2$ ([M + H]$^+$) 377.0033, found 377.0040.

5-(4-Iodo-5-methoxy-[1,1′-biphenyl]-3-yl)benzo[d][1,3]dioxole ***(4j)****:* yield 58%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59 (d, J = 7.2 Hz, 2H), 7.45−7.42 (m, 2H), 7.39−7.35 (m, 1H), 7.14 (d, J = 2.0 Hz, 1H), 6.98 (d, J = 2.0 Hz, 1H), 6.88−6.86 (m, 2H), 6.82 (dd, J = 8.0 Hz, 2.0 Hz, 1H), 6.02 (s, 2H), 3.99 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.7, 148.5, 147.0, 142.3, 140.2, 138.5, 128.9, 127.9, 127.1, 122.9, 121.7, 110.1, 108.3, 107.9, 101.1, 90.5, 56.7; IR (neat, cm^{-1}): 2922, 1558, 1494, 1454, 1390, 1243, 1220, 1093, 1037, 934, 854, 812, 762, 697, 660; HRMS (ESI) calcd for $C_{20}H_{15}IO_3$ ([M + H]$^+$) 431.0139, found 431.0141.

(E)-4-Iodo-3-methoxy-5-styryl-1,1′-biphenyl ***(4k)****:* yield 62%; light yellow solid; mp 150−152 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64−7.62 (m, 2H), 7.57 (d, J = 7.6 Hz, 2H), 7.51−7.45 (m, 4H), 7.41−7.36 (m, 3H), 7.31−7.29 (m, 1H), 7.02 (d, J = 16 Hz, 1H), 6.91 (d, J = 1.6 Hz, 1H), 3.96 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.6, 142.6, 142.4, 140.5, 136.9, 133.0, 132.0, 128.9, 128.7, 128.1, 127.8, 127.1, 126.9, 118.0, 108.7, 91.5, 56.7; IR (neat, cm^{-1}): 2920, 1580, 1548, 1448, 1384, 1075, 760, 695, 603; HRMS (ESI) calcd for $C_{21}H_{17}IO$ ([M + H]$^+$) 413.0397, found 413.0402.

4-Iodo-3-methoxy-5-propyl-1,1′-biphenyl ***(4l)****:* yield 51%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, J = 8.0 Hz, 2H), 7.36 (t, J = 8.0 Hz, 2H), 7.31−7.27 (m, 1H), 6.99 (s, 1H), 6.76 (s, 1H), 3.86 (s, 3H), 2.76−2.72 (m, 2H), 1.65−1.55 (m, 2H), 0.95 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.4, 147.4, 142.2, 140.6, 128.8, 127.6, 127.1, 121.0, 107.3, 91.7, 56.6, 43.3, 23.4, 13.9; IR (neat, cm^{-1}): 2923, 2855, 1560, 1455, 1392, 1223, 1076, 848, 761, 697, 610; HRMS (ESI) calcd for $C_{16}H_{17}IO$ ([M + H]$^+$) 353.0397, found 353.0395.

4′-Iodo-5′-methoxy-4-methyl-1,1′:3′,1″-terphenyl ***(4m)****:* yield 47%; light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (d, J = 8.0 Hz, 2H), 7.39−7.28 (m, 5H), 7.17−7.15 (m, 2H), 7.07 (d, J = 2.0 Hz, 1H), 6.91 (s, 1H), 3.91 (s, 3H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.6, 148.8, 144.6, 142.3, 137.7, 137.3, 129.6, 129.3, 127.9, 127.6, 126.9, 121.4, 108.2, 89.6, 56.7, 21.1; IR (neat, cm^{-1}): 2920, 1556, 1513, 1453, 1384, 1141, 1090, 1020, 813, 764, 700, 558; HRMS (ESI) calcd for $C_{20}H_{17}IO$ ([M + H]$^+$) 401.0397, found 401.0399.

4-Chloro-4′-iodo-5′-methoxy-1,1′:3′,1″-terphenyl ***(4n)****:* yield 35%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55−7.51 (m, 2H), 7.46−7.35 (m, 7H), 7.11 (d, J = 1.6 Hz, 1H), 6.95 (d, J = 1.6 Hz, 1H), 3.99 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.8, 149.1, 144.3, 141.1, 138.6, 134.0, 129.3, 129.0, 128.3, 127.9, 127.7, 121.4, 108.0, 90.5, 56.8, 56.7; IR (neat, cm^{-1}): 2911, 1558, 1447, 1382, 1082, 1016, 822, 759, 700; HRMS (ESI) calcd for $C_{19}H_{14}ClIO$ ([M + H]$^+$) 420.9851, found 420.9853.

4′-Iodo-4″,5′-dimethoxy-4-methyl-1,1′:3′,1″-terphenyl ***(4o)****:* yield 45%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (d, J = 8.0 Hz, 2H), 7.24−7.21 (m, 2H), 7.16−7.14 (m, 2H), 7.06 (d, J = 2.0 Hz, 1H), 6.88 (dd, J = 6.4 Hz, 2.0 Hz, 3H), 3.89 (s, 3H), 3.77 (s, 3H), 2.30 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 159.0, 158.6, 148.4, 142.2, 137.7, 137.3, 137.1, 130.5, 129.6, 126.9, 121.6, 113.2, 108.0, 90.1, 56.7, 56.7, 55.3, 55.2, 21.1, 21.1 IR (neat, cm^{-1}): 2924, 1609, 1555, 1511, 1459, 1385, 1245, 1177, 1140, 1087, 1026, 908, 813, 731, 583; HRMS (ESI) calcd for $C_{21}H_{19}IO_2$ ([M + H]$^+$) 431.0502, found 431.0502.

4-Chloro-4′-iodo-4″,5′-dimethoxy-1,1′:3′,1″-terphenyl ***(4p)****:* yield 57%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, J = 8.4 Hz, 2H), 7.34−7.31 (m, 2H), 7.22 (d, J = 8.8 Hz, 2H), 7.03 (d, J = 1.6 Hz, 1H), 6.89 (d, J = 8.8 Hz, 2H), 6.85 (d, J = 2.0 Hz, 1H), 3.91 (s, 3H), 3.79 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 159.1, 158.8, 148.7, 141.0, 138.7, 136.9, 133.9, 130.5, 129.0, 128.3, 121.6, 113.3, 107.8, 91.0, 56.7, 55.3; IR (neat, cm^{-1}): 2922, 1609, 1512, 1460, 1382, 1246, 1141, 1092, 1023, 887, 824, 707, 582; HRMS (ESI) calcd for $C_{20}H_{16}ClIO_2$ ([M + H]$^+$) 450.9956, found 450.9957.

4′,6‴-Diiodo-5′,5‴-dimethoxy-1,1′:3′,1″:4″,1‴:3‴,1⁗-quinquephenyl ***(4r)****:* yield 27%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73−7.62 (m, 5H), 7.49−7.43 (m, 8H), 7.40−7.36 (m, 2H), 7.22−7.13 (m, 1H), 7.03 (d, J = 1.6 Hz, 2H), [4.02 (s), 3.98 (s), 6H]; ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.7, 148.6, 143.7, 142.4, 140.2, 128.9, 128.9, 128.8, 127.9, 127.3, 127.1, 121.7, 108.4, 90.0, 56.8; IR (neat, cm^{-1}): 2923, 1592, 1459, 1384, 1151, 1069, 1021, 832, 762, 698, 576; HRMS (ESI) calcd for $C_{32}H_{24}I_2O_2$ ([M + H]$^+$) 694.9938, found 694.9944.

Characterization Data of 5a−q. *4′,5′-Diiodo-1,1′:3′,1″-terphenyl* ***(5a)****:* yield 70%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, J = 2.0 Hz, 1H), 7.47 (d, J = 7.2 Hz, 2H), 7.37−7.28 (m, 7H), 7.23 (d, J = 6.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 149.8, 146.6, 142.4, 138.4, 136.9, 129.0, 128.9, 128.2, 128.0, 127.9, 127.4, 126.9, 111.0, 110.7; IR (neat, cm^{-1}): 2922, 1576, 1530, 1493, 1446, 878, 757, 670, 573; HRMS (ESI) calcd for $C_{18}H_{12}I_2$ ([M + H]$^+$) 481.9023, found 481.9032.

5′,6′-Diiodo-4-methyl-1,1′:3′,1″-terphenyl ***(5b)****:* yield 52%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09−8.08 (m, 1H), 7.53 (dd, J = 7.2 Hz, 1.2 Hz, 2H), 7.43−7.34 (m, 4H), 7.25−7.19 (m, 4H), 2.42 (d, 1.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 149.8, 143.8, 142.4, 138.5, 137.7, 136.8, 129.0, 128.8, 128.7, 128.1, 127.4, 126.9, 111.3, 110.6, 21.3; IR (neat, cm^{-1}): 2920, 2852, 1575, 1534, 1505, 1447, 1385, 878, 817, 762, 695, 571; HRMS (ESI) calcd for $C_{19}H_{14}I_2$ ([M + H]$^+$) 495.9179, found 495.9185.

5′,6′-Diiodo-2,5-dimethoxy-1,1′:3′,1″-terphenyl ***(5e)****:* yield 20%; white colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (d, J = 1.6 Hz, 1H), 7.56−7.54 (m, 2H), 7.43−7.34 (m, 4H), 6.93−6.87 (m, 2H), 6.69 (d, J = 2.4 Hz, 1H), 3.78 (dd, J = 13.2 Hz, 6.4 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 153.2, 150.2, 146.7, 142.4, 138.6, 136.8, 136.2, 128.9, 128.1, 127.8, 127.0, 116.1, 114.3, 112.2, 56.2, 55.8; IR (neat, cm^{-1}): 2922, 2853, 1593, 1457, 1382, 1211, 1165, 1068, 853, 760, 696, 613; HRMS (ESI) calcd for $C_{20}H_{16}I_2O_2$ ([M + H]$^+$) 542.9312, found 542.9310.

4-Chloro-5′,6′-diiodo-1,1′:3′,1″-terphenyl ***(5f)****:* yield 63%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (d, J = 1.6 Hz, 1H), 7.53 (d, J = 7.2 Hz, 2H), 7.44−7.36 (m, 6H), 7.24 (d, J = 8.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 148.5, 144.8, 142.6, 138.3, 137.2, 134.0, 130.3, 129.0, 128.3, 126.9, 110.9, 110.8; IR (neat, cm^{-1}): 2922, 2865, 2361, 1665, 1599, 1463, 1384, 811, 763, 684, 658, 649; HRMS (ESI) calcd for $C_{18}H_{11}ClI_2$ ([M + H]$^+$) 515.8633, found 515.8639.

2-(4,5-Diiodo-[1,1′-biphenyl]-3-yl)thiophene ***(5h)****:* yield 20%; white oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (d, J = 2.0 Hz, 1H), 7.55−7.53 (m, 3H), 7.45−7.36 (m, 4H), 7.12−7.08 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 147.3, 142.3, 138.2, 137.6, 129.0, 128.8, 128.3, 127.8, 127.0, 126.6, 125.8, 112.6, 110.8; IR (neat, cm^{-1}): 2921, 2852, 1578, 1540, 1462, 1382, 1155, 1068, 762, 698; HRMS (ESI) calcd for $C_{16}H_{10}I_2S$ ([M + H]$^+$) 488.8665, found 488.8666.

5-(4,5-Diiodo-[1,1′-biphenyl]-3-yl)benzo[d][1,3]dioxole ***(5j)****:* yield 55%; light yellow solid; mp 53−55 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (d, J = 2.4 Hz, 1H), 7.55−7.53 (m, 2H), 7.44−7.34 (m, 4H), 6.85 (d, J = 8.0 Hz, 1H), 6.78−6.73 (m, 2H), 6.01 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 149.3, 147.3, 147.0, 142.4, 140.5, 138.4, 136.9, 129.0, 128.2, 127.5, 126.9, 122.5, 111.6, 110.5, 109.7, 107.9, 101.2; IR (neat, cm^{-1}): 2921, 1489, 1439, 1387, 1226, 1038, 937, 907, 813, 734, 697, 647, 565; HRMS (ESI) calcd for $C_{19}H_{12}I_2O_2$ ([M + H]$^+$) 526.8999, found 526.8999.

(E)-3,4-Diiodo-5-styryl-1,1′-biphenyl ***(5k)****:* yield 74%; white solid; mp 150−152 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, J = 2.0 Hz, 1H), 7.68 (d, J = 2.0 Hz, 1H), 7.55 (t, J = 8.8 Hz, 4H), 7.46−7.36 (m, 6H), 7.29 (t, J = 7.2 Hz, 1H), 6.87 (d, J = 16.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 144.2, 142.9, 138.8, 137.0, 136.4, 135.7, 132.9, 129.0, 128.8, 128.3, 128.2, 127.0, 126.9, 124.3, 111.8, 111.0; IR (neat, cm^{-1}): 2919, 1519, 1382, 1072, 1026, 952, 872, 763, 693, 545; HRMS (ESI) calcd for $C_{20}H_{14}I_2$ ([M + H]$^+$) 507.9179, found 507.9189.

4′,5′-Diiodo-4-methyl-1,1′:3′,1″-terphenyl ***(5m)****:* yield 12%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (d, J = 2.0 Hz, 1H), 7.44−7.38 (m, 6H), 7.29 (d, J = 8.0 Hz, 2H), 7.22 (d, J = 8.0 Hz, 2H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 149.7, 146.6, 142.3, 138.1, 136.7, 135.5, 129.7, 128.9, 128.0, 127.9, 127.2, 126.7, 110.6, 110.6, 21.1; IR (neat, cm^{-1}): 2919, 1361, 1512, 1386, 1025, 815,

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764, 738, 699, 568; HRMS (ESI) calcd for $C_{19}H_{14}I_2$ ([M + H]$^+$) 495.9179, found 495.9188.

*4′,5′-Diiodo-4″-methoxy-4-methyl-1,1′:3′,1″-terphenyl (**5o**):* yield 20%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (d, J = 2.4 Hz, 1H), 7.44−7.39 (m, 3H), 7.24−7.21 (m, 4H), 6.94 (d, J = 8.4 Hz, 2H), 3.85 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 159.2, 149.4, 142.3, 139.3, 138.1, 136.5, 135.5, 130.1, 129.7, 127.3. 126.7, 113.3, 111.2, 110.5, 55.3, 55.3, 21.1; IR (neat, cm^{-1}): 2920, 1609, 1509, 1384, 1247, 1034, 905, 814, 732, 573; HRMS (ESI) calcd for $C_{20}H_{16}I_2O$ ([M + H]$^+$) 526.9363, found 526.9363.

*1-(4,5-Diiodo-[1,1′-biphenyl]-3-yl)naphthalene (**5q**):* yield 43%; white solid; mp 54−56 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.20 (d, J = 2.0 Hz, 1H), 7.91 (d, J = 8.4 Hz, 2H), 7.57−7.48 (m, 6H), 7.45−7.31 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 148.3, 144.3, 142.4, 138.3, 137.1, 133.5, 131.0, 129.0, 128.4, 128.3, 128.2, 128.2, 126.9, 126.5, 126.4, 126.1, 125.8, 125.2, 112.6, 110.4; IR (neat, cm^{-1}): 2922, 2852, 1530, 1389, 1074, 1026, 906, 879, 768, 731, 695, 583; HRMS (ESI) calcd for $C_{22}H_{14}I_2$ ([M + H]$^+$) 531.9179, found 531.9191.

Characterization Data of 2aa, 4aa, 4ab, and 5ab. *5′-Ethoxy-1,1′:3′,1″-terphenyl (**2aa**):* yield 25%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65−7.63 (m, 4H), 7.45 (t, J = 7.6 Hz, 4H), 7.39−7.35 (m, 3H), 7.11 (d, J = 1.2 Hz, 2H), 4.16 (q, J = 6.8 Hz, 2H), 1.47 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 159.7, 143.1, 141.2, 128.8, 127.5, 127.3, 118.8, 112.4, 63.7, 14.9; IR (neat, cm^{-1}): 2922, 2853, 1596, 1461, 1383, 1195, 1069, 1044, 868, 759, 698; HRMS (ESI) calcd for $C_{20}H_{18}O$ ([M + H]$^+$) 275.1430, found 275.1435.

*5′-Ethoxy-4′-iodo-1,1′:3′,1″-terphenyl (**4aa**):* yield 57%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60−7.58 (m, 2H), 7.46−7.36 (m, 8H), 7.15 (d, J = 1.6 Hz, 1H), 6.98 (d, J = 1.6 Hz, 1H), 4.22 (q, J = 6.8 Hz, 2H), 1.55 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.2, 148.9, 144.6, 142.2, 140.2, 129.3, 128.9, 128.7, 127.9, 127.8, 127.6, 127.3, 127.1, 121.5, 109.6, 90.9, 65.4, 14.9; IR (neat, cm^{-1}): 2924, 1558, 1495, 1448, 1389, 1228, 1138, 1043, 861, 761, 698, 587; HRMS (ESI) calcd for $C_{20}H_{17}IO$ ([M + H]$^+$) 401.0397, found 401.0398.

*5′-Methoxy-4′-(phenylethynyl)-1,1′:3′,1″-terphenyl (**4ab**):* yield 65%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, J = 7.2 Hz, 2H), 7.58−7.56 (m, 2H), 7.40−7.36 (m, 4H), 7.34−7.29 (m, 2H), 7.27−7.25 (m, 2H), 7.21−7.16 (m, 4H), 7.04 (d, J = 1.6 Hz, 1H), 3.95 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 160.8, 146.1, 142.2, 140.6, 140.5, 131.3, 129.5, 128.8, 128.1, 127.9, 127.8, 127.6, 127.2, 123.8, 120.9, 110.2, 108.1, 97.4, 85.5, 56.2, 56.2; IR (neat, cm^{-1}): 3057, 1594, 1552, 1492, 1458, 1404, 1344, 1021, 758, 696; HRMS (ESI) calcd for $C_{27}H_{20}O$ ([M + H]$^+$) 361.1587, found 361.1594.

*4′,5′-Bis(phenylethynyl)-1,1′:3′,1″-terphenyl (**5ab**):* yield 96%; red oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, J = 2.0 Hz, 1H), 7.73−7.71 (m, 2H), 7.66 (d, J = 7.2 Hz, 2H), 7.63−7.61 (m, 3H), 7.51−7.43 (m, 5H), 7.38−7.34 (m, 6H), 7.27 (dd, J = 5.2 Hz, 1.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 144.8, 140.7, 140.4, 139.5, 131.7, 131.4, 129.4, 129.2, 128.9, 128.5, 128.4, 128.3, 128.0, 128.0, 128.0, 127.8, 127.2, 127.1, 127.0, 123.5, 123.3, 123.0, 97.3, 93.5, 88.8, 88.2; IR (neat, cm^{-1}): 3057, 2921, 1595, 1542, 1492, 1384, 1069, 1025, 911, 756, 694, 595; HRMS (ESI) calcd for $C_{34}H_{22}$ ([M]$^+$) 430.1716, found 430.1729.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Text giving additional experimental details and figures giving analytical data for all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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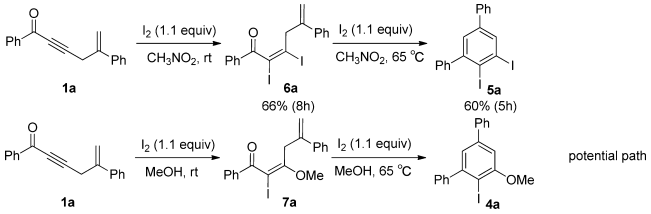
(11) Intermediate **6a** was isolated in 66% yield after 8 h. When **6a** was subjected to the same reaction conditions (with high temperature), **5a** was obtained in 60% after 5 h (see below). Meanwhile, **1a** in MeOH at room temperature was also likely to generate intermediate **7a** with a fast conversion rate, which could not be observed by TLC and isolated for high activity. Therefore, we considered it as a potential path with **7a** as an intermediate.



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