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Cyanides-Free Cyanation of Aryl Halides using Formamide

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Abstract: A novel method for cyanation of aryl halides using formamide as a non-toxic cyanide source is reported. It is a single-step, solvent-free method wherein formamide itself acts as solvent as well as source of cyanide in the presence of phosphorus oxychloride and palladium acetate/xantphos catalyst. Aryl iodides as well as aryl bromides provided moderate to excellent yields of up to 93%.

Keywords: aryl halides; C–C coupling; cyanation; formamide; nitriles; palladium

Introduction

Cyanation is an important tool for the introduction of various functionalities such as carboxylic acids, aldehydes, ketones, oximes, amides, amines, azoles, and oxazolidines in aromatic and heteroaromatic rings.[1] Hence, aryl nitriles have great industrial importance for the synthesis of chemicals, dyes, natural products, therapeutic drugs and their intermediates.[2] Cyanation of aryl halides is the most common method used for the synthesis of aryl nitriles. The Rosenmund–von Braun[3] and Sandmeyer[4] reactions are most traditional methods used for cyanation of aryl halides, which require stoichiometric amounts of toxic CuCN and harsh reaction conditions. Recent developments in the transition metal-catalyzed methodologies for the preparation of aryl nitriles from aryl halide has changed the scenario[5] and for which many palladium-, copper-, or nickel-catalyzed cyanation protocols have been explored.[6] Among these, palladium was widely investigated for the cyanation of aryl halides. Most of these protocols requires highly toxic and environmentally hazardous cyanide sources such as KCN,[7] NaCN,[8] CuCN,[9] $Zn(CN)_2$,[10] trimethylsilyl cyanide,[11] acetone cyanohydrins,[12] etc., restricting their applications. A synthesis of nitriles using milder reagents like $K_4[Fe(CN)_6]$[13] has also been reported. Although $K_4[Fe(CN)_6]$ is easy to handle, it should be noted that it is also derived from a conventional metal cyanide source. Recently, *N*-cyanobenzimidazole was also used as cyanide source for aryl halides.[14] however, it requires drastic reaction conditions, use of Grignard reagents and the preparation of cyanoimidazole using bromocyanogen which is a toxic cyanide source, so limiting its application.

Considering these issues, we focused our attention towards the development of a novel cyanide-free protocol for the synthesis of nitriles. Herein, we report a simple, non-toxic, efficient and cyanide-free, single-step protocol for the cyanation of aryl halides using formamide as a cyanide source. It was observed that amides can be synthesized from aryl halides using a strategy of CO-free aminocarbonylation *via* reaction of dimethylformamide (DMF).[15] We planned to extend this concept further for nitrile synthesis for the first time wherein formamide can be replace the DMF and with a suitable catalyst it can be converted to nitriles (see Scheme 1).

Results and Discussion

The synthesis of benzonitrile (**3a**) from formamide (**2a**) and iodobenzene (**1a**) using $Pd(OAC)_2$/dppf as catalytic system and $POCl_3$ as an additive was investigated. It has been observed that benzonitrile was formed as a single product (38%) along with unreacted iodobenzene (Table 1, entry 5). Based on these preliminary results, the reaction parameters for the cyanation reaction were optimized. Test experiments to check the roles of every component in reaction system were performed (Table 1). They show that

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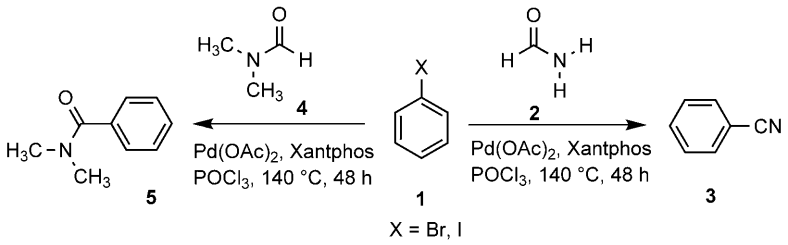
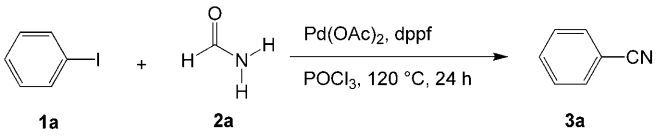


Scheme 1. Cyanides-free cyanation of aryl halides using formamide.

Table 1. Test experiment for cyanides-free cyanation of iodobenzene (**1a**) with formamide (**2a**).[a]



Entry	$Pd(OAc)_2$	**L2**	$POCl_3$	**1a**	**2a**	Yield [%][b]
1	–	–	✓	✓	✓	0
2	–	✓	✓	✓	✓	0
3	✓	–	✓	✓	✓	traces
4	✓	✓	–	✓	✓	0
5	✓	✓	✓	✓	✓	38

[a] *Reaction conditions:* **1a** (1.0 mmol), **2a** (10 mL mmol^{-1}), $Pd(OAc)_2$ (5 mol%), **L2** (10 mol%), $POCl_3$ (2.0 mmol), 120 °C, 24 h under nitrogen atmosphere.
[b] GC yield.

$Pd(OAC)_2$, dppf and $POCl_3$ were all necessary for the title reaction (Table 1, entries 1–5).

Various bidentate phosphine ligands as shown in Figure 1 were investigated for the cynation reaction (Table 2). The best result was obtained with Xantphos ligand (54%, Table 2, entry 1) while most of the other ligands were found to be ineffective (Table 2, entries 3–6).

It was observed that $Pd(OAc)_2$ provided higher yields than other palladium precursors (Table 2, entries 1, 7 and 8). The yield was increased with the reaction temperature range from 130–150 °C, in which 140 °C reflects to be optimum temperature (Table 2, entries 9–13). The reaction time was also optimized (Table 2, entries 14–17) and a maximum yield of product **3a**, that is, 89% yield was obtained after 48 h (Table 2, entry 16). The effect of catalyst loading ranging from 1–7 mol% of substrate for the model reaction was studied and it was observed that increasing the catalyst loading from 1 mol% to 5 mol% led to a remarkable increase in the yield of the desired product (Table 3, entries 1–5). Furthermore, we also investigated the effect of the metal to ligand ratio, whereby a 1:2 ratio was found to be optimal (Table 3, entry 3).

A brief survey of the $POCl_3$ concentration effect was also performed and optimal results were achieved using 2 equivalents of $POCl_3$ (Table 4, entries 1–5).

Studies on the effect of the formamide concentration revealed that 8–10 mL mmol^{-1} formamide are essential for higher yields of the desired product (Table 5, entries 4 and 5).

Thus, the optimized reaction conditions are iodobenzene (**1a**, 1 mmol), $Pd(OAc)_2$ (0.05 mmol), Xantphos (0.10 mmol) and $POCl_3$ (2 mmol) in formamide (**2a**, 10 mL mmol^{-1} of iodobenzene) at 140 °C for 48 h.

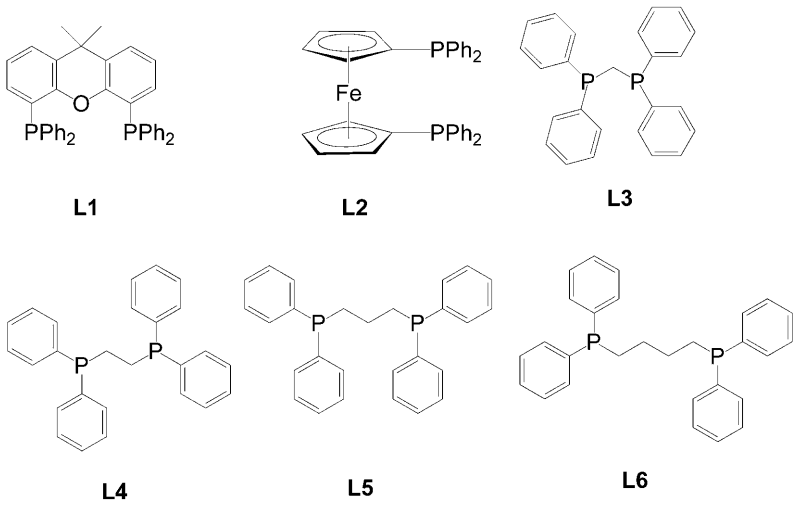


Figure 1. Structures of the ligands **L1–L6**.

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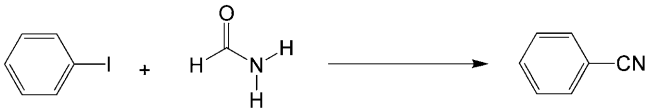
Table 2. Optimization for the cyanides-free cyanation reaction of iodobenzene (**1a**) with formamide (**2a**).[a]



1a **2a** **3a**

Entry	Ligand	Pd catalyst	Temp. [°C]	Time [h]	Yield [%][b]
Effect of ligand					
1	**L1**	$Pd(OAc)_2$	120	24	54
2	**L2**	$Pd(OAc)_2$	120	24	40
3	**L3**	$Pd(OAc)_2$	120	24	0
4	**L4**	$Pd(OAc)_2$	120	24	0
5	**L5**	$Pd(OAc)_2$	120	24	0
6	**L6**	$Pd(OAc)_2$	120	24	0
Effect of metal precursor					
7	**L1**	$PdCl_2$	120	24	42
8	**L1**	$Pd(acac)_2$	120	24	26
Effect of temprature					
9	**L1**	$Pd(OAc)_2$	130	24	57
10	**L1**	$Pd(OAc)_2$	135	24	61
11	**L1**	$Pd(OAc)_2$	140	24	69
12	**L1**	$Pd(OAc)_2$	145	24	70
13	**L1**	$Pd(OAc)_2$	150	24	71
Effect of time					
14	**L1**	$Pd(OAc)_2$	140	36	77
15	**L1**	$Pd(OAc)_2$	140	42	81
16	**L1**	$Pd(OAc)_2$	140	48	89
17	**L1**	$Pd(OAc)_2$	140	54	91

[a] *Reaction conditions:* **1a** (1.0 mmol), **2a** (10 mL mmol^{-1}), Pd precursor (5 mol%), ligand (10 mol%), $POCl_3$ (2.0 mmol), under nitrogen.
[b] GC yield.

Table 3. Influence of catalyst loading on cyanides-free cyanation.[a]

Entry	$Pd(OAc)_2$ (mol%)	**L1** (mol%)	Yield of **3a** [%][b]
1	1	2	42
2	2.5	5	68
3	5	10	89
4	5	5	72
5	7	14	90

[a] *Reaction conditions:* **1a** (1.0 mmol), **2a** (10 mL mmol^{-1}), $Pd(OAc)_2$, **L1**, $POCl_3$ (2.0 mmol), 140 °C, 48 h, under nitrogen.
[b] GC yield.

In order to study the scope and generality of the present protocol, different types of aryl halides containing electron-donating groups were reacted with formamide and they gave good to excellent yields of the desired product (Table 6). We found that different aryl halides such as aryl bromides, aryl iodides were converted to the corresponding aryl nitriles under these conditions. It was observed that *ortho*-substituted substrates are well tolerated providing excellent yields of desired products (Table 6, entries 4 and 5). Iodonaphthalene provided the highest yield 93% of the expected product (Table 6, entry 6), while β-substitution of a methoxy group in 1-iodonapthalene led to a decrease in yield (Table 6, entry 7). The method is also useful for the preparation of heterocyclic nitriles. Heterocyclic iodides such as 2-iodothiophene, 5-iodoindole also gave good yields (Table 6, entries 8 and 9). It is noteworthy to mention that the present methodology was successfully applied to aryl bromides which are known to be difficult substrates and it delivered moderate yield in range of 49–66% of yield.

Table 4. Influence of $POCl_3$ concentration on cyanides-free cyanation.[a]

Entry	$POCl_3$ (mmol)	Yield of **3a** [%][b]
1	0.5	42
2	1.0	69
3	1.5	76
4	2.0	87
5	2.5	88

[a] *Reaction conditions:* **1a** (1.0 mmol), **2a** (10 mL mmol^{-1}), $Pd(OAc)_2$ (5 mol%), **L1** (10 mol%), $POCl_3$, 140 °C, 48 h, under nitrogen.
[b] GC yield.

Table 5. Influence of formamide concentration on cyanides-free cyanation.[a]

Entry	Formamide (mL)	Yield of **3a** [%][b]
1	2	20
2	4	65
3	6	82
4	8	87
5	10	91

[a] *Reaction conditions:* **1a** (1.0 mmol), **2a**, $Pd(OAc)_2$ (5 mol%), **L1** (Xantphos) (10 mol%), $POCl_3$ (2.0 mmol), 140 °C, 48 h, under nitrogen.
[b] GC yield.

They showed the same pattern of reactivity as was observed for aryl iodides, that is, electron-rich aryl bromides giving good yields (Table 6, entries 10–12). *ortho*-Substituted aryl bromides give moderate yields (Table 6, entries 13 and 14) and 1-bromonapthalene gives the maximum yield of the expected product (Table 6, entry 15). To our surprise, when diiodobenzene was treated with formamide under the same conditions phthalimide was obtained as a product instead of dinitrile (Table 6, entry 16). To the best of our knowledge this is the first example of a CO-free synthesis of phthalimide from diiodobenzene. Aryl chlorides were found to be ineffective for this reaction. It

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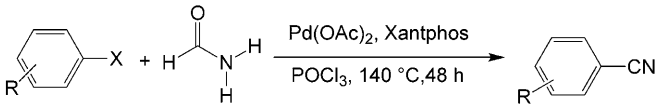
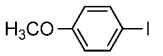
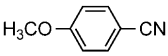
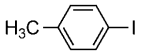
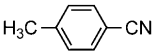
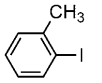
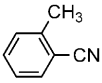
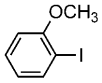
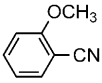
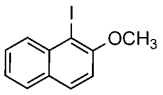
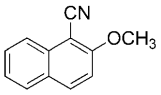
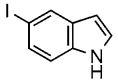
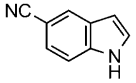
Table 6. Scope of cyanides-free cyanation of aryl halides using formamide (**2a**).[a]



1 (x = I or Br) **2a** **3**

Entry	Aryl halide	Product		Yield [%][b]
1			**3a**	81
2			**3b**	89
3			**3c**	84
4			**3d**	87
5			**3e**	91
6			**3f**	93
7			**3g**	78
8			**3h**	59
9			**3i**	67
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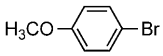
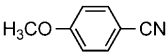
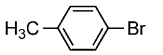
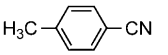
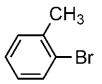
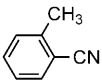
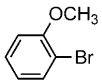
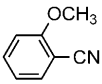
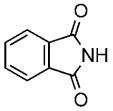
11			**3b**	56
12			**3c**	53
13			**3d**	50
14			**3e**	57
15			**3f**	66
16			**6a**	72

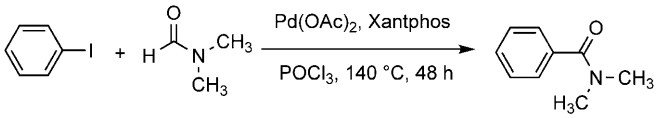
[a] *Reaction conditions:* **1** (1.0 mmol), **2a** (10 mL mmol^{-1}), $Pd(OAc)_2$ (5 mol%), **L1** (10 mol%), $POCl_3$ (2.0 mmol), 140 °C, 48 h under nitrogen.

[b] Yield of isolated product after column chromatography.

is worthy of note that the reaction also produces a stoichiometric amount of salt as a by-product after reaction because of $POCl_3$.

Mechanism

To probe the mechanism of the studied transformation, the reaction of iodobenzene was performed with DMF instead of formamide under the same reaction conditions wherein the aminocarbonylated product was obtained instead of the expected benzonitrile (Scheme 2). As DMF does not have a free hydrogen



1a **4a** **5a** (92 %)

Scheme 2. Reaction of iodobenzene with DMF to predict the possible mechanism.

it did not undergo dehydration giving the aminocarbonylated product. This is a major difference in our work and previous work reported by Hiyama and coworkers[15a] and they did not observe nitriles in the case of formamide probably due to a lack of the right catalyst. On the grounds of results obtained, we assume that the reaction of formamide with iodobenzene might be involving benzamide as an intermediate which on dehydration could give benzonitrile. In a substrate study it was observed that diiodobenzene gave pthalamide instead of the nitrile (Table 6, entry 14) which also supports the hypothesis, that is, the reaction involves aminocarbonylation, therefore as soon as amide is formed it prefers cyclization instead of dehydration and forms phthalimide.

From the previous report on CO-free aminocarbonylation[15] and the results obtained, we predict that our nitrile synthesis involves oxidative insertion of Pd into the C–X bond which produces an aryl palladium halide intermediate **1** (Scheme 3). Thereafter, an iminium salt (Vilsmeier-type reagent) undergoes nucleophilic addition of the aryl palladium halide to form **3**, which then undergoes β-hydride elimination forming intermediate **4**, which is a key intermediate of the reaction. In case of formamide, intermediate **4** undergoes aminocarbonylation followed by dehydration to give nitriles, while in the case of the DMF reaction it gives an aminocarbonylated product as there is no free hydrogen. As earlier reported by Hosoi et al.[15a] the formation of Vilsmeier reagent in this case is essential for the reaction to occur and no base is employed to regenerate Pd(0) from the hydro palladium halide species (H–Pd–X).[15a]

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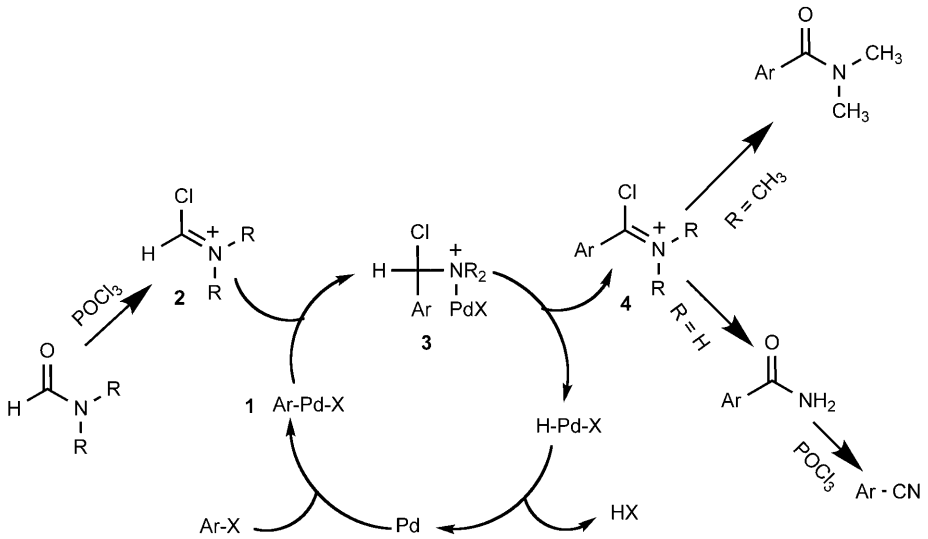

Scheme 3. Proposed mechanism for the cyanation.

Conclusions

In summary, we have reported a novel, non-toxic and convenient methodology for the cyanation of aryl halides using formamide as cyanide source. The process is a one-step reaction where no extra solvent is required as formamide acts as solvent as well as source of cyanide. These advantages thus suggest that the developed protocol might prove to be an attractive alternative to the reported methods for nitrile synthesis. Further applications of protocol and studies on the CO-free synthesis of phthalimide are under progress.

Experimental Section

Materials and Methods

All the chemicals were purchased from Sigma Aldrich, Lancaster (Alfa-Aesar), S. D. fine chemical and commercial suppliers. All reactions were carried out under a nitrogen atmosphere. The progress of the reaction was monitored by thin layer chromatography using Merck silica gel 60 F254 plates. The product was visualized with a 254 nm UV lamp. Products were purified by column chromatography on silica gel (60–120) mesh. All yields reported in Table 6 (entries 1–16) refer to isolated yields of pure compounds as determined by ^{1}H NMR while yields reported in Table 1–Table 5 are GC yields. All products are well known compounds and identified by ^{1}H NMR, ^{13}C NMR, GC-MS, FT-IR data that were compared with previously reported data. ^{1}H NMR and ^{13}C NMR spectra were recorded with a JEOL FT-NMR, Model-AL300 (300 MHz) spectrometer in $CDCl_3$. Chemical shifts are reported in parts per million (δ) relative to tetamethylsilane as internal standard. *J* (coupling constants) are reported in Hz, splitting patterns of proton are described as s (singlet), d (doublet), t (triplet), m (multiplet). Mass spectra were obtained on a Shimadzu GCMS-QP 2010 instrument. The IR spectra were recorded with FT-IR (Perkin–Elmer). GC analysis was carried out on Perkin–Elmer (Clarus-400) gas chromatography equipped with flame ionization detector with a capillary column (Elite-1, 30 m × 0.32 mm × 0.25 μm).

General Experimental Procedure for Cyanide-Free Cynation Reactions

A mixture of aryl halide (1 mmol), $Pd(OAc)_2$ (5 mol%) and Xantphos (10 mol%) in formamide (10 mL mmol^{-1}) was placed in a 25-mL two-necked round-bottom flask equipped with a condenser at room temperature under nitrogen. Then $POCl_3$ (2 mmol) was added to the reaction mixture which was placed in an oil bath and magnetically stirred at 140 °C for 48 h under complete nitrogen atmosphere. After completion, the reaction mixture was cooled to room temperature and was poured into a saturated solution of $NaHCO_3$ (50 mL). The product was extracted with diethyl ether (4 × 20 mL). The combined organic layers were dried over Na_2SO_4 and evaporated to afford the crude product which was then purified by column chromatography on silica gel (using petroleum ether/diethyl ether or petroleum ether/ethyl acetate combination) to afford the pure product. The products are well known and were confirmed by IR, GC-MS, ^{1}H and ^{13}C NMR spectroscopic analysis.

General Experimental Procedure for Test Experiments

A mixture of iodobenzene (1 mmol), $Pd(OAc)_2$ (5 mol%) and Xantphos (10 mol%) in DMF (10 mL mmol^{-1}) was placed in a 25-mL two-necked round-bottom flask equipped with a condenser at room temperature under nitrogen. Then $POCl_3$ (2 mmol) was added to the reaction mixture which was placed in oil bath with magnetical stirring at 140 °C for 48 h under complete nitrogen atmosphere. After completion, the reaction mixture was cooled to room temperature and was poured into a saturated solution of $NaHCO_3$ (50 mL). The product was extracted with diethyl ether (4 × 20 mL). The combined organic layers were dried over

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Na_2SO_4 and evaporated to afford the crude product which was purified by column chromatography on silica gel (using petroleum ether/diethyl ether or petroleum ether/ethyl acetate combination) to afford the pure product. The product was confirmed by IR, GC-MS, ^1H and ^{13}C NMR spectroscopic analysis.

Benzonitrile (3a) (Table 6, entries 1 and 10): Colourless liquid; ^1H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 7.67–7.58$ (m, 3H), 7.50–7.45 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 132.5, 131.7, 128.8, 118.5, 111.9$; GC-MS (EI, 70 eV): *m/z* (%) = 103 (M^+, 100), 76 (41), 50 (13); IR (neat): $\nu = 2228$ (C≡N), 1598, 1490, 1447, 757, 687, 547 cm^{-1}.

4-Methoxybenzonitrile (3b) (Table 6, entries 2 and 11): White solid; ^1H NMR (400 MHz, $CDCl_3$, 25 °C): $\delta = 7.55$ (d, $J = 8.7$ Hz, 2H), 6.92 (d, $J = 8.7$ Hz, 2H), 3.83 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 162.8, 133.9, 119.2, 114.7, 103.8, 55.5$; GC-MS (EI, 70 eV): *m/z* (%) = 133 (M^+, 100), 103 (46), 90 (45), 76 (12), 63 (16); IR (neat): $\nu = 2219$ (C≡N), 1605, 1675, 1509, 1462, 1259, 1176, 1023, 828, 683, 546 cm^{-1}.

4-Methylbenzonitrile (3c) (Table 6, entries 3 and 12): Colourless liquid; ^1H NMR (400 MHz, $CDCl_3$, 25 °C): $\delta = 7.53$ (d, $J = 8.3$ Hz, 2H), 7.26 (d, $J = 8.3$ Hz, 2H), 2.42 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 143.5, 131.7, 129.6, 118.9, 109, 21.6$; GC-MS (EI, 70 eV): *m/z* (%) = 117 (M^+, 100), 116 (61), 90 (44), 89 (26), 63 (13); IR (neat): $\nu = 2228$ (C≡N), 1607, 1508, 816, 546 cm^{-1}.

2-Methylbenzonitrile (3d) (Table 6, entries 4 and 13): Yellowish liquid; ^1H NMR (400 MHz, $CDCl_3$, 25 °C): $\delta = 7.60–7.45$ (m, 2H), 7.26–7.32 (m, 2H), 2.55 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 142, 132.7, 132.5, 130.2, 126.2, 119.1, 112.8, 20.5$; GC-MS (EI, 70 eV): *m/z* (%) = 117 (M^+, 100), 116 (53), 90 (54), 89 (31), 63 (13); IR (neat): $\nu = 2226$ (C≡N), 1606, 1487, 762 cm^{-1}.

2-Methoxybenzonitrile (3e) (Table 6, entries 5 and 14): Light yellow solid; ^1H NMR (400 MHz, $CDCl_3$, 25 °C): $\delta = 7.57–7.52$ (m, 2H), 7.03–6.97 (m, 2H), 3.92 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 161.7, 134.4, 133.6, 120.7, 116.5, 111.2, 101.6, 55.9$; GC-MS (EI, 70 eV): *m/z* (%) = 133 (M^+, 100), 132 (29), 104 (88), 90 (45), 76 (19), 63 (29); IR (neat): $\nu = 2228$ (C≡N), 1599, 1492, 1288, 1260, 1165, 1112, 1020, 811, 755, 729 cm^{-1}.

1-Cyanonaphthalene (3f) (Table 6, entries 6 and 15): White solid; ^1H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 8.22$ (d, $J = 8.4$ Hz, 1H), 8.06 (d, $J = 8.0$ Hz, 1H), 7.92–7.88 (m, 2H), 7.70–7.48 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 133.3, 132.9, 132.6, 132.4, 128.7, 128.6, 127.6, 125.1, 124.9, 117.9, 110.2$; GC-MS (EI, 70 eV): *m/z* (%) = 153 (M^+, 100), 126 (21), 76 (8), 63 (10); IR (neat): $\nu = 2222$ (C≡N), 800, 771 cm^{-1}.

1-Cyano-2-methoxynaphthalene (3g) (Table 6, entry 7): White solid; ^1H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 8.02–8.10$ (m, 2H), 7.83 (d, $J = 8.4$ Hz, 1H), 7.64 (t, $J = 7.3$, 7.6 Hz, 1H), 7.45 (t, $J = 7.33$, 7.6 Hz, 1H), 7.27 (d, $J = 9$ Hz); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 161.7, 135.1, 133.6, 129.2, 128.5, 128, 125.1, 124.1, 115.7, 112.1, 56.6$; GC-MS (EI, 70 eV): *m/z* (%) = 183 (M^+, 100), 167 (11), 154 (13), 140 (84), 113 (18), 63 (10); IR (neat): $\nu = 2212$ (C≡N), 1625, 1594, 1508, 1284 1262, 1085, 808, 749, 684 cm^{-1}.

2-Cyanothiazole (3h) (Table 6, entry 8): Light yellow oil; ^1H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 7.13$ (dd, $J = 3.9$, 5.1, 1H), 7.49–7.66 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ 137.8, 131.8, 128, 114.6, 110.2; GC-MS (EI, 70 eV): *m/z* (%) = 109 (M^+, 100), 82 (10), 58 (34), 57 (9), 45 (31).

5-Cyanoindole (3i) (Table 6, entry 9): Yellowish solid; ^1H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 8.60$ (bs, 1H), 8.0 (s, 1H), 7.47 (d, $J = 8.8$ Hz, 1H,), 7.42 (dd, $J = 1.2$, 8.8 Hz, 1H), 7.34 (t, $J = 2.8$ Hz, 1H), 6.64–6.63 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 137.6, 127.7, 126.8, 126.4, 124.7, 121.1, 112.2, 103.2, 102.3$; GC-MS (EI, 70 eV): *m/z* (%) = 142 (M^+, 100), 115 (39), 114 (18), 88 (11).

Phthalimide (6a) (Table 6, entry 16): White solid; ^1H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 7.81$ (s, 4H), 11.33 (bs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 169.2, 134.2, 132.6, 122.9$; GC-MS (EI, 70 eV): *m/z* (%) = 147 (M^+, 100), 104 (58), 76 (54), 50 (21).

***N,N*-Dimethylbenzamide (5a) (Scheme 2):** Yellowish solid; ^1H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.9$ (s, 3H), 3.1 (s, 3H), 7.4 (s, 5H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 171.7, 136.4, 129.6, 128.4, 127.1, 39.6, 35.4$; GC-MS (EI, 70 eV): *m/z* (%) = 149 (28), 148 (61), 105 (M^+, 100), 77 (61), 51 (18).

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