Conversion of *N*-benzyloxycarbonylamino- and *N*-tosylamino-benzyl phenylsulfones by green Strecker reactions to α-aminobenzyl nitriles using potassium hexacyanoferrate(II)

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The cyanation of aldimines, generated *in situ* from *N*-benzyloxycarbonylamino- and *N*-tosylamino-benzyl phenylsulfones, to the corresponding *N*-protected α-aminobenzyl nitriles has been achieved by eco-friendly Strecker reactions using potassium hexacyanoferrate(II) as a cyanide source, benzoyl chloride as a promoter, and potassium hydroxide as a base. The protocol has the advantages of using a nontoxic, nonvolatile and inexpensive cyanating agent, employing a simple work-up procedure and producing high yields.

Keywords: *N*-benzyloxycarbonylaminobenzyl phenylsulfone, *N*-tosylaminobenzyl phenylsulfone, potassium hexacyanoferrate(II), α-aminobenzyl nitrile, green Strecker reaction

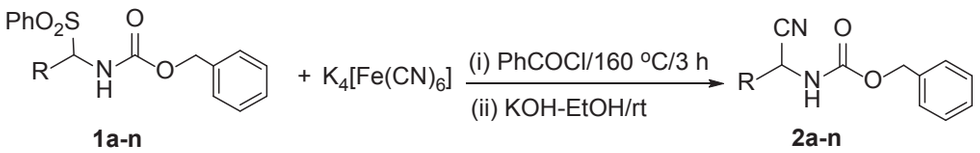
The Strecker reaction, now understood as the nucleophilic addition of cyanide ion to imines, is of great importance to modern organic chemistry as it offers one of the most direct and viable methods for the synthesis of α-aminonitriles.[1] α-Amido sulfones, which are considered as a useful precursor of *N*-protected imines[2] and therefore can directly participate in Strecker reactions under appropriate conditions, can be easily prepared by a three-component coupling of the corresponding aldehyde, sodium sulfinate and carbamate in the presence of formic acid.[3] Under basic conditions, α-amido sulfones are readily converted to *N*-protected imines that can further react with various nucleophiles.[4,5] Recently several authors demonstrated Strecker reactions of α-amido sulfones using different cyanide sources. Ooi[6] and Reingruber[7] reported the synthesis of *N*-*p*-tolylsulfonyl α-amino nitriles from α-amido *p*-tolylsulfones using aqueous potassium cyanide in the presence of a phase transfer catalyst. Herrear[8] described Strecker reactions of α-amido *p*-tolylsulfones to synthesise *N*-*t*-butyloxycarbonyl α-amino nitriles using acetone cyanohydrin as a cyanating agent. Kim[9] and Das[10] reported the synthesis of *N*-benzyloxycarbonyl α-amino nitriles from α-amido *p*-tolylsulfones using trimethylsilyl cyanide as cyanating agent in the presence of bismuth bromide or indium chloride. However, some problems are still associated with the use of these cyanating agents including renowned toxicity of potassium cyanide, volatility of acetone cyanohydrin, and moisture unstability of trimethylsilyl cyanide. To overcome these problems, attention has been given to the development of alternative cyanide sources that are cheap, less toxic, and easier to handle.

$K_4[Fe(CN)_6]$ is a by-product of the chemical coal industry and is commercially available on a ton scale, and is cheaper than KCN. Recently, $K_4[Fe(CN)_6]$ has been used as a cyanide source for some substitution reactions to synthesise benzonitriles,[11–14] aroyl cyanides,[15] arylsulfonyl cyanide,[16] benzyl cyanides,[17] and cinnamonitriles.[18] Our research work has focused on the cyanation of unsaturated compounds including C=O,[19–22] C=N [23–26] or C=C[27–28] bonds by nucleophilic addition reactions using $K_4[Fe(CN)_6]$ as an eco-friendly cyanide source. Here we report the cyanation of aldimines, generated *in situ* from *N*-benzyloxycarbonylamino- and *N*-tosylamino-benzyl phenylsulfones, to the corresponding *N*-benzyloxycarbonyl and *N*-tosyl α-aminobenzyl nitriles by Strecker reactions using potassium hexacyanoferrate(II) as an eco-friendly cyanide source, benzoyl chloride as a promoter, and potassium hydroxide as a base.

Results and discussion

Initially, *N*-benzyloxycarbonylaminobenzyl phenylsulfone **1a** (Scheme 1, R = Ph) was selected as a test substrate to investigate the Strecker reaction using potassium hexacyanoferrate(II) ($K_4[Fe(CN)_6]$) as an eco-friendly cyanide source to synthesise α-(*N*-benzyloxycarbonylamino)benzyl nitrile **2a** (Scheme 1, R = Ph). A preliminary treatment of $K_4[Fe(CN)_6]$ with benzoyl chloride (160 °C/3 h) was necessary in order to generate benzoyl cyanide. Upon cooling this mixture to room temperature, **1a** was added and the mixture stirred in EtOH (10 mL) under different conditions using various bases. It was found that no product was given in the absence of a base, nor in the presence of sodium carbonate (Table 1, entries 1 and 2). Some bases, such as pyridine and NaOH were totally ineffective. Et_3N and DMAP did give the desired product α-(*N*-benzyloxycarbonylamino) benzyl nitrile **2a** in moderate yield in 7 h (Table 1, entries 3 and 4), but K_2CO_3 (80%) and KOH (87%) gave very good yields in just 0.5 h (Table 1, entries 6 and 7).

Further research using KOH as a base showed that solvents also played a crucial role in the Strecker reaction of **1a** with $K_4[Fe(CN)_6]$ (Table 2). It was found that no product was observed



1a-n **2a-n**

Scheme 1 Cyanation of *N*-benzyloxycarbonylaminobenzyl phenylsulfones.

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Table 1 The effect of various bases and the duration of reaction on the yield of cyanation of *N*-benzyloxycarbonylaminobenzyl phenylsulfone **1a** by $K_4[Fe(CN)_6]$(Scheme 1)[a]

Entry	Base	Time/h	Yield/%[b]
1	none	24	NR[c]
2	Na_2CO_3	24	NR[c]
3	Et_3N	7	54
4	DMAP	7	40
5	K_2CO_3	0.5	80
6	KOH	0.5	87

[a]Reaction conditions: $K_4[Fe(CN)_6]$ (0.4 mmol), benzoyl chloride (2.4 mmol), N-benzyloxycarbonylaminobenzyl phenylsulfone **1a** (2.0 mmol) and base (3.0 mmol) in EtOH (10 mL) were stirred at room temperature.
[b]Isolated yields.
[c]Unidentified by-products were observed.

Table 2 The effect of solvents and the duration of reaction on the yield of cyanation of *N*-benzyloxycarbonylaminobenzyl phenylsulfone **1a** by $K_4[Fe(CN)_6]$(Scheme 1)[a]

Entry	Solvent	Time (h)	Yield/%[b]
1	DMF	24	NR[c]
2	Et_2O	24	NR[c]
3	MeOH	1	45
4	MeCN	1	51
5	CH_2Cl_2	2	58
6	EtOH	0.5	87

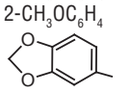
[a]Reaction conditions: $K_4[Fe(CN)_6]$ (0.4 mmol), benzoyl chloride (2.4 mmol), *N*-benzyloxycarbonylaminobenzyl phenylsulfone **1a** (2.0 mmol) and potassium hydroxide (3.0 mmol) in solvent (10 mL) were stirred at room temperature.
[b]Isolated yields.
[c]Unidentified by-products were observed.

in some solvents, such as PhMe, THF and $CHCl_3$. Reaction in Et_2O and DMF gave unidentified by-products (Table 2, entries 1 and 2), but reaction in some solvents, such as MeOH, MeCN and CH_2Cl_2, gave the desired product in moderate yields (Table 2, entries 3–5). However, EtOH was found to be the best solvent for the reaction affording the desired product in the highest yield within the shortest time (Table 2, entry 6).

Based on the above promising findings, two kinds of α-amido sulfones, *N*-benzyloxycarbonylaminobenzyl phenylsulfones (Scheme 1) and *N*-tosylaminobenzyl phenylsulfones (Scheme 2), were examined for the Strecker reactions using $K_4[Fe(CN)_6]$ as an eco-friendly cyanide source, benzoyl chloride as a promoter, and potassium hydroxide as a base in ethanol.

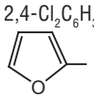
N-Benzyloxycarbonylaminobenzyl phenylsulfones containing electron-donating groups (MeO and Me) or electron-withdrawing substituents (F, Cl and Br) on aromatic rings of R were successfully converted into the corresponding α-amino nitriles in high yield (Table 3, entries 2–13). This indicated that the electronic effect of the substituents had little impact on the reaction yield. On the other hand, *N*-benzyloxycarbonylamino phenylsulfone bearing a furan heterocycle underwent reaction to form the corresponding product in only moderate yield

Table 3 The yields/reaction times of the cyanation of *N*-benzyloxycarbonylaminobenzyl phenylsulfone **1a–n** using $K_4[Fe(CN)_6]$ as a cyanide source (Scheme 1)[a]

Entry	R	Product	Time/h	Yield/%[b]
1	C_6H_5	**2a**	4	87
2	2-$CH_3C_6H_4$	**2b**	4	91
3	4-$CH_3C_6H_4$	**2c**	4	93
4	4-$CH_3OC_6H_4$	**2d**	4	95
5	3-$CH_3OC_6H_4$	**2e**	4	87
6	2-$CH_3OC_6H_4$	**2f**	4	82
7		**2g**	4	96
8	4-FC_6H_4	**2h**	5	93
9	2-FC_6H_4	**2i**	5	85
10	2-ClC_6H_4	**2j**	5	91
11	4-ClC_6H_4	**2k**	5	94
12	2,4-$Cl_2C_6H_3$	**2l**	6	88
13	4-BrC_6H_4	**2m**	6	88
14		**2n**	6	63

[a]Reaction conditions: $K_4[Fe(CN)_6]$ (0.4 mmol), benzoyl chloride (2.4 mmol), *N*-benzyloxycarbonylaminobenzyl phenylsulfone **1a–n** (2.0 mmol) and potassium hydroxide (3.0 mmol) in EtOH (10 mL) were stirred at room temperature.
[b]Isolated yields.

Table 4 The yields/reaction times of the cyanation of *N*-tosylaminobenzyl phenylsulfones **3a–g** using $K_4[Fe(CN)_6]$ as a cyanide source (Scheme 2)[a]

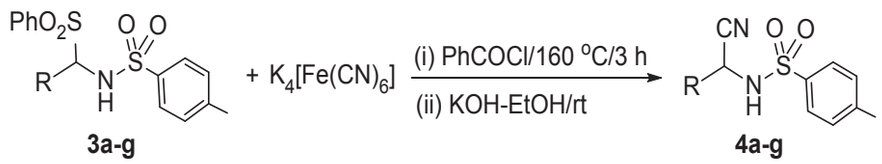
Entry	R	Product	Time/h	Yield/%[b]
1	C_6H_5	**4a**	3.5	93
2	4-$CH_3C_6H_4$	**4b**	3.5	95
3	4-ClC_6H_4	**4c**	4	90
4	2,4-$Cl_2C_6H_3$	**4d**	4	88
5		**4e**	4	78
6	CH_3CH_2	**4f**	3.5	80
7	$(CH_3)_2CH$	**4g**	3.5	81

[a]Reaction conditions: $K_4[Fe(CN)_6]$ (0.4 mmol), benzoyl chloride (2.4 mmol), *N*-tosylaminobenzyl phenylsulfones **3a–g** (2.0 mmol) and potassium hydroxide (3.0 mmol) in EtOH (10 mL) were stirred at room temperature.
[b]Isolated yields.

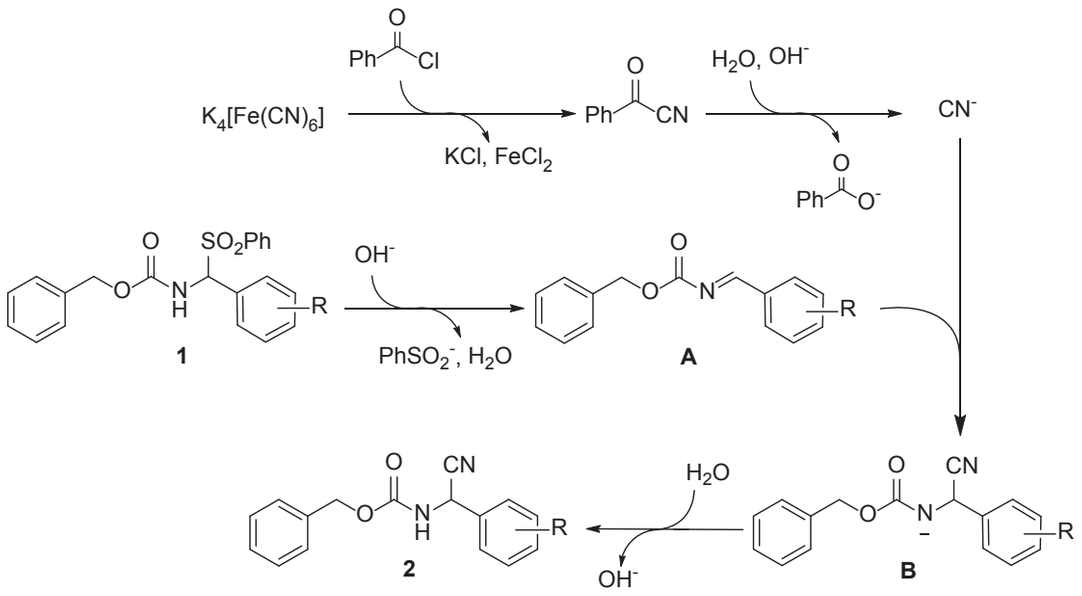
(Table 3, entry 14). Unfortunately an attempt of a similar reaction with *N*-benzyloxycarbonylaminobenzyl phenylsulfone with an NO_2 group on the aromatic ring of R was not successful, and unidentified by-products were observed.

The cyanation of *N*-tosylaminobenzyl phenylsulfones was also examined under similar conditions using $K_4[Fe(CN)_6]$ as an eco-friendly cyanide source (Table 4). *N*-tosylamino-x-benzyl phenylsulfones gave high yields (entries 1–4). Other analogues containing a furyl or an alkyl group (entries 5–7) gave good yields.

A plausible mechanism for the Strecker reactions of *N*-benzyloxycarbonylaminobenzyl phenylsulfones with



Scheme 2 Cyanation of *N*-tosylaminobenzyl phenylsulfones.



Scheme 3 The proposed mechanism for the cyanation of *N*-benzyloxycarbonylaminobenzyl phenylsulfones with $K_4[Fe(CN)_6]$.

$K_4[Fe(CN)_6]$ to synthesise *N*-benzyloxycarbonyl α-aminobenzyl nitriles is shown in Scheme 3. $K_4[Fe(CN)_6]$ first reacts with benzoyl chloride to form benzoyl cyanide as an intermediate, which can be isolated and identified.[28] Then benzoyl cyanide is attacked by water from undried solvent in the presence of hydroxyl ion to produce cyanide ion *in situ*. *N*-Benzyloxycarbonylaminobenzyl phenylsulfones **1** transform into *N*-benzyloxycarbonyl imines **A** in the presence of potassium hydroxide by elimination of benzensulfinate. Then the intermediate **A** undergoes nucleophilic addition by CN^- to give intermediates **B**, which combine with hydrogen ions from water to give the corresponding addition products **2**.

Experimental

IR spectra were recorded using KBr pellets on an Alpha Centauri FTIR spectrophotometer. NMR spectra were obtained on a Mercury-400BB spectrometer (^{1}H NMR at 400 Hz, ^{13}C NMR at 100 Hz) in $CDCl_3$ using TMS as internal standard. Chemical shifts (δ) are given in ppm and coupling constants (*J*) in Hz. Elemental analyses were performed on a Vario El Elemental Analysis instrument. Melting points were determined in an electrothermal melting point apparatus. Potassium hexacyanoferrate(II) was dried at 80 °C under vacuum for 24 h and finely powdered prior to use. *N*-Benzyloxycarbonylamino- and *N*-tosylamino-benzyl phenylsulfones were prepared according to literature procedures.[29,30]

Cyanation of N-*benzyloxycarbonylamino- and* N-*tosylamino-benzyl phenylsulfones to synthesise* N-*benzyloxycarbonyl and* N-*tosyl α-aminobenzyl nitriles; general procedure*

A mixture of $K_4[Fe(CN)_6]$ (0.4 mmol) and benzoyl chloride (2.4 mmol) was heated at 160 °C for 3 h, then the reaction system was cooled to room temperature. *N*-Benzyloxycarbonylamino- or *N*-tosylamino-benzyl phenylsulfones (2.0 mmol) and potassium hydroxide (3.0 mmol) in 10 mL of ethanol were then added. The resulting mixture was further stirred at room temperature for an appropriate time which is indicated in Tables 3 and 4. The progress of the reaction was monitored by TLC. After the completion of reaction, the reaction mixture was concentrated and the residue was subject to silica gel flash column chromatography using petroleum ether and ethyl acetate as eluent to obtain the pure products. The analytical data of all products are given below.

Benzyl cyano(phenyl)methylcarbamate (**2a**): White solid; m.p. 102–104 °C (EtOAc); IR (KBr, ν_{max}): 3277 (NH), 1696 (C=O) cm^{-1}; ^{1}H NMR: δ 5.21 (s, 2H, CH_2), 5.51 (bs, 1H, NH), 5.88 (d, *J* = 8.4 Hz, 1H, CH), 7.40–7.51 (m, 10H, ArH) ppm; ^{13}C NMR: δ 46.52, 67.91, 117.37, 126.89, 128.87, 128.50, 128.60, 129.35, 129.65, 132.94, 135.37, 154.96 ppm. Anal. calcd for $C_{16}H_{14}N_2O_2$: C, 72.17; H, 5.30; N, 10.52; found: C, 72.05; H, 5.28; N, 10.49%.

Benzyl cyano(o-tolyl)methylcarbamate (**2b**): White solid; m.p. 102–103 °C (EtOAc); IR (KBr, ν_{max}): 3310 (NH), 1688 (C=O) cm^{-1}; ^{1}H NMR: δ 2.36 (s, 3H, CH_3), 5.17 (s, 2H, CH_2), 5.25 (d, *J* = 7.4 Hz, 1H, NH), 5.91 (d, *J* = 7.4 Hz, 1H, CH), 7.23–7.35 (m, 8H, ArH), 7.58 (d, *J* = 7.6 Hz, 1H, ArH) ppm; ^{13}C NMR: δ 18.78, 44.59, 67.86, 117.65, 126.92, 127.43, 128.24, 128.48, 128.60, 129.94, 130.87, 131.41, 135.40, 136.16, 154.71 ppm. Anal. calcd for $C_{17}H_{16}N_2O_2$: C, 72.84; H, 5.75; N, 9.99; found: C, 72.96; H, 5.77; N, 10.01%.

Benzyl cyano(p-tolyl)methylcarbamate (**2c**): White solid; m.p. 106–108 °C (EtOAc); IR (KBr, ν_{max}): 3282 (NH), 2253 (CN), 1670 (C=O) cm^{-1}; ^{1}H NMR: δ 2.29 (s, 3H, CH_3), 5.08 (s, 2H, CH_2), 5.29 (bs, 1H, NH), 5.71 (d, *J* = 8.4 Hz, 1H, CH), 7.16 (d, *J* = 8.4 Hz, 2H, ArH), 7.24–7.28 (m, 7H, ArH) ppm; ^{13}C NMR: δ 21.13, 46.33, 67.85, 117.53, 126.83, 128.28, 128.49, 128.61, 129.99, 135.42, 139.77, 154.94 ppm. Anal. calcd for $C_{17}H_{16}N_2O_2$: C, 72.84; H, 5.75; N, 9.99; found: C, 72.76; H, 5.73; N, 9.95%.

Benzyl cyano(p-methoxyphenyl)methylcarbamate (**2d**): White solid; m.p. 105–106 °C (EtOAc); IR (KBr, ν_{max}): 3297 (NH), 2243 (CN), 1689 (C=O) cm^{-1}; ^{1}H NMR: δ 3.73 (s, 3H, CH_3), 5.08 (s, 2H, CH_2), 5.30 (bs, 1H, NH), 5.68 (d, *J* = 8.0 Hz, 1H, CH), 6.83–6.86 (m, 2H, ArH), 7.27–7.32 (m, 7H, ArH) ppm; ^{13}C NMR: δ 46.05, 55.37, 67.83, 114.64, 117.61, 124.92, 128.27, 128.35, 128.47, 128.60, 135.42, 154.90, 160.45 ppm. Anal. calcd for $C_{17}H_{16}N_2O_3$: C, 68.91; H, 5.44; N, 9.45; found: C, 68.83; H, 5.43; N, 9.48%.

Benzyl cyano(3-methoxyphenyl)methylcarbamate (**2e**): White solid; m.p. 72–74 °C (EtOAc); IR (KBr, ν_{max}): 3313 (NH), 2250 (CN), 1703 (C=O) cm^{-1}; ^{1}H NMR: δ 3.79 (s, 3H, CH_3), 5.15 (s, 2H, CH_2), 5.61 (bs, 1H, NH), 5.79 (d, *J* = 7.6 Hz, CH), 6.91–7.05 (m, 3H, ArH), 7.29–7.34 (m, 6H, ArH) ppm; ^{13}C NMR: δ 46.42, 55.33, 67.85, 112.47, 115.12, 117.34, 118.93, 128.21, 128.42, 128.55, 130.40, 134.42, 135.42, 155.05, 160.14 ppm. Anal. calcd for $C_{17}H_{16}N_2O_3$: C, 68.91; H, 5.44; N, 9.45; found: C, 68.87; H, 5.45; N, 9.43%.

Benzyl cyano(2-methoxyphenyl)methylcarbamate (**2f**): White solid; m.p. 92–94 °C (EtOAc); IR (KBr, ν_{max}): 3316 (NH), 2248 (CN), 1712 (C=O) cm^{-1}; ^{1}H NMR: δ 3.91 (s, 3H, CH_3), 5.14 (s, 2H, CH_2), 5.85 (m, 2H, NH, CH), 6.95–7.00 (m, 2H, ArH), 7.34–7.42 (m, 7H, ArH) ppm;

^{13}C NMR: δ 43.53, 55.78, 67.69, 111.48, 117.63, 121.12, 121.60, 128.31, 128.41, 128.57, 129.13, 131.32, 135.63, 154.94, 156.99 ppm. Anal. calcd for $C_{17}H_{16}N_2O_3$: C, 68.91; H, 5.44; N, 9.45; found: C, 68.78; H, 5.46; N, 9.42%.

Benzyl benzo[d][1,3]dioxol-5-yl(cyano)methylcarbamate (**2g**): White solid; m.p. 94–96 °C (EtOAc); IR (KBr, ν_{max}): 3320 (NH), 2275 (CN), 1703 (C=O) cm^{-1}; ^{1}H NMR: δ 5.16 (s, 2H, CH_2), 5.38 (d, *J* = 8.0 Hz, 1H, NH), 5.73 (d, *J* = 8.0 Hz, 1H, CH), 5.99 (s, 2H, CH_2), 6.81–6.97 (m, 4H, ArH), 7.32–7.36 (m, 4H, ArH) ppm; ^{13}C NMR: δ 46.28, 67.91, 101.70, 107.35, 108.71, 117.42, 120.80, 126.64, 128.29, 128.52, 128.62, 135.38, 148.50, 148.72, 154.88 ppm. Anal. calcd for $C_{17}H_{14}N_2O_4$: C, 65.80; H, 4.55; N, 9.03; found: C, 65.71; H, 4.56; N, 9.00%.

Benzyl cyano(4-fluorophenyl)methylcarbamate (**2h**): White solid; m.p. 93–94 °C (EtOAc); IR (KBr, ν_{max}): 3281 (NH), 2251 (CN), 1684 (C=O) cm^{-1}; ^{1}H NMR: δ 5.16 (s, 2H, CH_2), 5.60 (bs, 1H, NH), 5.82 (d, *J* = 8.0 Hz, 1H, CH), 7.09–7.17 (m, 2H, ArH), 7.36–7.46 (m, 7H, ArH) ppm; ^{13}C NMR: δ 45.79, 67.93, 116.24, 116.46, 117.21, 128.26, 128.52, 128.59, 128.85, 128.93, 135.24, 154.96, 161.91, 164.39 ppm. Anal. calcd for $C_{16}H_{13}FN_2O_2$: C, 67.60; H, 4.61; N, 9.85; found: C,67.75; H, 4.60; N, 9.82%.

Benzyl cyano(2-fluorophenyl)methylcarbamate (**2i**): White solid; m.p. 102–103 °C (EtOAc); IR (KBr, ν_{max}): 3316 (NH), 1684 (C=O) cm^{-1}; ^{1}H NMR: δ 5.17 (s, 2H, CH_2), 5.57 (bs, 1H, NH), 5.98 (d, *J* = 8.8 Hz, 1H, CH), 7.15–7.25 (m, 2H, ArH), 7.37–7.55 (m, 7H, ArH) ppm; ^{13}C NMR: δ 41.75, 67.94, 116.26, 116.46, 116.60, 120.80, 124.91, 124.95, 128.27, 128.49, 128.59, 129.12, 131.90, 131.97, 135.31, 154.68, 158.90, 161.39 ppm. Anal. calcd for $C_{16}H_{13}FN_2O_2$: C, 67.60; H, 4.61; N, 9.85; found: C, 67.54; H, 4.63; N, 9.88%.

Benzyl cyano(2-chlorophenyl)methylcarbamate (**2j**): White solid; m.p. 112–114 °C (EtOAc); IR (KBr, ν_{max}): 3313 (NH), 1701 (C=O) cm^{-1}; ^{1}H NMR: δ 4.89 (s, 2H, CH_2), 5.32 (bs, 1H, NH), 5.80 (d, *J* = 8.4 Hz, 1H, CH), 7.05–7.21 (m, 8H, ArH), 7.36 (d, *J* = 7.6 Hz, 1H, ArH) ppm; ^{13}C NMR: δ 44.79, 67.91, 116.69, 127.66, 128.25, 128.47, 128.58, 129.45, 130.54, 130.63, 131.24, 133.29, 135.35, 154.67 ppm. Anal. calcd for $C_{16}H_{13}ClN_2O_2$: C, 63.90; H, 4.36; N, 9.31; found: C, 63.85; H, 4.35; N, 9.28%.

Benzyl cyano(4-chlorophenyl)methylcarbamate (**2k**): White solid; m.p. 98–99 °C (EtOAc); IR (KBr, ν_{max}): 3319 (NH), 1699 (C=O) cm^{-1}; ^{1}H NMR: δ 5.17 (s, 2H, CH_2), 5.40 (bs, 1H, NH), 5.84 (d, *J* = 8.4 Hz, 1H, CH), 7.36–7.43 (m, 9H, ArH) ppm; ^{13}C NMR: δ 45.94, 68.09, 116.98, 128.28, 128.34, 128.61, 128.66, 129.59, 131.53, 135.26, 135.83, 154.92 ppm. Anal. calcd for $C_{16}H_{13}ClN_2O_2$: C, 63.90; H, 4.36; N, 9.31; found: C, 63.99; H, 4.38; N, 9.34%.

Benzyl cyano(2,4-dichlorophenyl)methylcarbamate (**2l**): White solid; m.p. 92–93 °C (EtOAc); IR (KBr, ν_{max}): 3290 (NH), 2249 (CN), 1697 (C=O) cm^{-1}; ^{1}H NMR: δ 4.76 (s, 2H, CH_2), 5.40 (bs, 1H, NH), 5.63 (d, *J* = 8.0 Hz, 1H, CH), 6.90–7.08 (m, 7H, ArH), 7.19 (d, *J* = 8.0 Hz, 1H, ArH) ppm; ^{13}C NMR: δ 44.37, 68.16, 116.54, 128.06, 128.41, 128.68, 128.76, 129.46, 130.42, 134.19, 135.39, 136.77, 154.96 ppm. Anal. calcd for $C_{16}H_{12}Cl_2N_2O_2$: C, 57.33; H, 3.61; N, 8.36; found: C,57.41; H, 3.60; N, 8.33%.

Benzyl cyano(4-bromophenyl)methylcarbamate (**2m**): White solid; m.p. 102–104 °C (EtOAc); IR (KBr, ν_{max}): 3321 (NH), 1698 (C=O) cm^{-1}; ^{1}H NMR: δ 5.09 (s, 2H, CH_2), 5.34 (bs, 1H, NH), 5.74 (d, *J* = 8.4 Hz, 1H, CH), 7.18–7.32 (m, 7H, ArH), 7.48 (d, *J* = 8.4 Hz, 1H, ArH) ppm; ^{13}C NMR: δ 45.99, 68.10, 116.92, 123.97, 128.34, 128.53, 128.61, 128.66, 132.07, 132.54, 135.24, 154.92 ppm. Anal. calcd for $C_{16}H_{13}BrN_2O_2$: C, 55.67; H, 3.80; N, 8.12; found: C, 55.79; H, 3.79; N, 8.09%.

Benzyl cyano(furan-2-yl)methylcarbamate (**2n**): White solid; m.p. 78–80 °C (EtOAc); IR (KBr, ν_{max}): 3296 (NH), 2268 (CN), 1691 (C=O) cm^{-1}; ^{1}H NMR: δ 5.08 (s, 2H, CH_2), 5.56 (d, *J* = 8.0 Hz, 1H, NH), 5.95 (d, *J* = 9.6 Hz, 1H, CH), 6.25–6.27 (m, 2H, Fu-H), 7.18–7.29 (m, 6H, ArH, Fu-H) ppm; ^{1}H NMR: δ 58.42, 67.19, 107.26, 110.24, 128.14, 128.27, 128.55, 136.03, 142.58, 151.26 ppm. Anal. calcd for $C_{14}H_{12}N_2O_3$: C, 65.62; H, 4.72; N, 10.93; found: C, 65.57; H, 4.70; N, 10.89%.

N-(Cyanophenylmethyl)-4-methylbenzenesulfonamide (**4a**): White solid; m.p. 152–154 °C (EtOAc); IR (KBr, ν_{max}): 3254 (NH), 2245 (CN), 1334 (S=O asym), 1157 (S=O sym) cm^{-1}; ^{1}H NMR: δ 2.46 (s, 3H, CH_3), 5.10 (d, *J* = 8.4 Hz, 1H, NH), 5.48 (d, *J* = 8.4 Hz, 1H, CH), 7.36–7.46 (m, 8H, ArH), 7.82 (t, *J* = 8.4 Hz, 2H, ArH) ppm; ^{13}C NMR: δ 21.62, 48.16, 116.19, 127.01, 127.28, 129.36, 129.87, 130.02, 131.99, 135.91, 144.70 ppm. Anal. calcd for $C_{15}H_{14}N_2O_2S$: C, 62.92; H, 4.93; N, 9.78; found: C, 62.84; H, 4.92; N, 9.81%.

N-(Cyano(4-tolyl)methyl)-4-methylbenzenesulfonamide (**4b**): White solid; m.p. 149–150 °C (EtOAc); IR (KBr, ν_{max}): 3270 (NH), 2248 (NH), 1336 (S=O asym), 1160 (S=O sym) cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 2.28 (s, 3H, CH_3), 2.38 (s, 3H, CH_3), 5.08 (d, *J* = 8.4 Hz, 1H, NH), 5.34 (d, *J* = 8.4 Hz, 1H, CH), 7.12 (d, *J* = 8.0 Hz, 2H, ArH), 7.23 (d, *J* = 8.0 Hz, 2H, ArH), 7.28 (d, *J* = 8.0 Hz, 2H, ArH), 7.72 (d, *J* = 8.0 Hz, 2H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 21.12, 21.62, 47.94, 116.42, 126.96, 127.30, 129.14, 129.98, 136.05, 139.99, 144.58 ppm. Anal. calcd for $C_{16}H_{16}N_2O_2S$: C, 63.98; H, 5.37; N, 9.33; found: C, 64.10; H, 5.39; N, 9.30%.

N-(4-Chlorophenyl(cyano)methyl)-4-methylbenzenesulfonamide (**4c**): White solid; m.p. 130–132 °C (EtOAc); IR (KBr, ν_{max}): 3262 (NH), 2249 (CN), 1342 (S=O asym), 1160 (S=O sym) cm^{-1}; ^{1}H NMR: δ 2.46 (s, 3H, CH_3), 5.30 (d, *J* = 9.2 Hz, 1H, NH), 5.45 (d, *J* = 9.2 Hz, 1H, CH), 7.35–7.39 (m, 6H, ArH), 7.77 (d, *J* = 8.4 Hz, 2H, ArH) ppm; ^{13}C NMR: δ 21.60, 47.54, 115.96, 127.20, 128.46, 129.47, 130.03, 130.62, 135.78, 135.95, 144.80 ppm. Anal. calcd for $C_{15}H_{13}ClN_2O_2S$: C, 56.16; H, 4.08; N, 8.73; found: C, 56.09; H, 4.10; N, 8.75%.

N-(Cyano(2,4-dichlorophenyl)methyl)-4-methylbenzenesulfonamide (**4d**): White solid; m.p. 136–137 °C (EtOAc); IR (KBr, ν_{max}): 3248 (NH), 2248 (CN), 1343 (S=O asym), 1158 (S=O sym) cm^{-1}; ^{1}H NMR: δ 2.44 (s, 3H, CH_3), 5.51 (s, 1H, NH), 5.63 (d, *J* = 8.8 Hz, 1H, CH), 7.28–7.32 (m, 3H, ArH), 7.37 (s, 1H, ArH), 7.44 (d, *J* = 8.4 Hz, 1H, ArH), 7.72 (d, *J* = 8.0 Hz, 2H, ArH) ppm; ^{13}C NMR: δ 21.70, 45.71, 115.53, 127.30, 128.09, 128.42, 129.97, 130.34, 130.44, 133.90, 135.73, 137.02, 144.84 ppm. Anal. calcd for $C_{15}H_{12}Cl_2N_2O_2S$: C, 50.72; H, 3.41; N, 7.89; found: C, 50.81; H, 3.40; N, 7.91%.

N-(Cyano(furan-2-yl)methyl)-4-methylbenzenesulfonamide (**4e**): White solid; m.p. 98–100 °C (EtOAc); IR (KBr, ν_{max}): 3277 (NH), 2251 (CN), 1337 (S=O asym), 1161 (S=O sym) cm^{-1}; ^{1}H NMR: δ 2.44 (s, 3H, CH_3), 5.37 (d, *J* = 9.2 Hz, 1H, NH), 5.53 (d, *J* = 9.2 Hz, 1H, CH), 6.34–6.35 (m, 1H, Fu-H), 6.47 (d, *J* = 3.6 Hz, 1H, Fu-H), 7.34 (d, *J* = 8.4 Hz, 2H, ArH), 7.38 (s, 1H, Fu-H), 7.77 (d, *J* = 8.4 Hz, 2H, ArH) ppm; ^{13}C NMR: δ 21.85, 42.44, 110.55, 111.04, 114.71, 127.29, 131.22, 135.90, 143.90, 144.48, 144.82 ppm. Anal. calcd for $C_{13}H_{12}N_2O_3S$: C, 56.51; H, 4.38; N, 10.14; found: C, 56.43; H, 4.37; N, 10.11%.

N-(1-Cyanopropyl)-4-methylbenzenesulfonamide (**4f**): White solid; m.p. 52–54 °C (EtOAc); IR (KBr, ν_{max}): 3283 (NH), 2249 (CN), 1333 (S=O asym), 1161 (S=O sym) cm^{-1}; ^{1}H NMR: δ 0.95–0.96 (m, 3H, CH_3), 2.01–2.04 (m, 2H, CH_2), 2.44 (s, 3H, CH_3), 4.69 (d, *J* = 9.2 Hz, 1H, CH), 5.12 (bs, 1H, NH), 7.26–7.36 (m, 2H, ArH), 7.77–7.79 (m, 2H, ArH) ppm; ^{13}C NMR: δ 13.25, 21.28, 21.60, 51.16, 116.00, 126.03, 127.25, 129.94, 134.24, 136.15, 144.49 ppm. Anal. calcd for $C_{11}H_{14}N_2O_2S$: C, 55.44; H, 5.92; N, 11.76; found: C, 55.56; H, 5.90; N, 11.73%.

N-(1-Cyano-2-methylpropyl)-4-methylbenzenesulfonamide (**4g**): White solid; m.p. 78–79 °C (EtOAc); IR (KBr, ν_{max}): 3281 (NH), 2240 (CN), 1339 (S=O asym), 1162 (S=O sym) cm^{-1}; ^{1}H NMR: δ 1.04 (d, *J* = 6.8 Hz, 6H, CH_3), 1.99–2.07 (m, 1H, CH), 2.44 (s, 3H, CH_3), 4.01–4.05 (m, 1H, CH), 5.53 (bs, 1H, NH), 7.35 (d, *J* = 7.6 Hz, 2H, ArH), 7.78 (d, *J* = 7.6 Hz, 2H, ArH) ppm; ^{13}C NMR: δ 17.80, 18.48, 21.69, 32.38, 50.61, 116.75, 127.23, 130.08, 135.96, 144.56 ppm. Anal. calcd for $C_{12}H_{16}N_2O_2S$: C, 57.12; H, 6.39; N, 11.10; found: C, 57.05; H, 6.41; N, 11.07%.

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References

1 H. Groger, *Chem. Rev.*, 2003, **103**, 2795.
2 M. Petrini, *Chem. Rev.*, 2005, **105**, 3949.
3 T. Mecozzi and M. Petrini, *J. Org. Chem*., 1999, **64**, 8970.
4 J. Song, H.W. Shih and L. Deng, *Org. Lett*., 2007, **9**, 603.
5 A.L. Tillman, J. Ye and D.J. Dixon, *Chem. Commun*., 2006, 1191.
6 T. Ooi, Y. Uematsu, J. Fujimoto, K. Fukumoto and K. Maruoka, *Tetrahedron Lett*., 2007, **48**, 1337.
7 R. Reingruber, T. Baumann, S. Dahmen and S. Bräse, *Adv. Synth. Catal*., 2009, **351**, 1019.
8 R.P. Herrera, V. Sgarzani, L. Bernardi, F. Fini, D. Pettersen and A. Ricci, *J. Org. Chem*., 2006, **71**, 9869.
9 S.T. Kadam, P. Thirupathi and S.S. Kim, *Tetrahedron*, 2010, **66**, 1684.
10 B. Das, K. Damodar, B. Shashikanth, Y. Srinivas and I. Kalavathi, *Synlett*, 2008, **20**, 3133.
11 T. Schareina, A. Zapf and M. Beller, *J. Organomet. Chem*., 2004, **689**, 4576.
12 R. Gerber, M. Oberholzer and C.M. Frech, *Chem. Eur. J*., 2012, **18**, 2978.
13 P.Y. Yeung, C.P. Tsang and F.Y. Kwong, *Tetrahedron Lett*., 2011, **52**, 7038.
14 P.Y. Yueng, M.S. Chau, P.L. Chak, *Org. Lett.,* 2011, **13**, 648.
15 Z. Li, S.Y. Shi and J.Y. Yang, *Synlett*, 2006, 2495.
16 Z. Li and J. Xu, *Phosphorus, Sulfur Silicon Relat. Elem.,* 2014, **189**, 374.
17 Y.L. Ren, C.H. Dong, S. Zhao, Y.P. Sun, J.J. Wang, J.Y. Ma and C.D. Hou, *Tetrahedron Lett*., 2012, **53**, 2825.
18 D. Saha, L. Adak, M. Mukherjee and B.C. Ranu, *Org. Biomol. Chem*., 2012, **10**, 952.
19 Z.X. Zhao and Z. Li, *Eur. J. Org. Chem*., 2010, 5460.
20 Z.X. Zhao and Z. Li, *J. Braz. Chem. Soc*., 2011, **22**, 148.
21 X.C. Hu, Z.X. Zhao and Z. Li, *Phosphorus Sulfur Silicon Relat. Elem*., 2012, **187**, 1003.
22 Z. Li, G.Q. Tian and Y.H. Ma, *Synlett*, 2010, **14**, 2164.
23 X.C. Hu, Y.H. Ma and Z. Li, *J. Organomet. Chem*., 2012, **705**, 70.
24 Z. Li, Y.H. Ma, J. Xu, J.H. Shi and H.F. Cai, *Tetrahedron Lett*., 2010, **51**, 3922.
25 Z. Li, R.Z. Li, H.H. Zheng, F. Wen, H.B. Li, J.J. Yin and J.Y. Yang, *J. Braz. Chem. Soc.,* 2013, **24**, 1739.
26 Z. Li, P.X. Niu, R.Z. Li, Y.P. Zhang, B. Ma and J.Y. Yang, *J. Chem. Res*., 2012, **36**, 709.
27 Z. Li, C.H. Liu, Y.P. Zhang, R.Z. Li, B. Ma and J.Y. Yang, *Synlett*, 2012, **23**, 2567.
28 Z. Li, Y.P. Zhang, F. Wen, J.J. Yin, H.H. Zheng, H.B. Li and J.Y. Yang, *J. Chem. Res.,* 2013, **37**, 601.
29 A.L. Tillmana, J.X. Ye and D.J. Dixon, *Chem. Commun*., 2006, 1191.
30 A.M. Kanazawa, J.N. Denis and A.E. Greene, *J. Org. Chem*., 1994, **59**, 1238.