Copper(I) Halide Mediated Tandem 1,4-Aryl Migration–Oxidative Amidyl Radical Cyclisation of Bromosulfonamides

Andrew J. Clark,* David R. Fullaway, Nicholas P. Murphy, Hemal Parekh

Department of Chemistry, University of Warwick, Coventry, West Midlands, CV4 7AL, UK
Fax +44(2476)524112; E-mail: a.j.clark@warwick.ac.uk

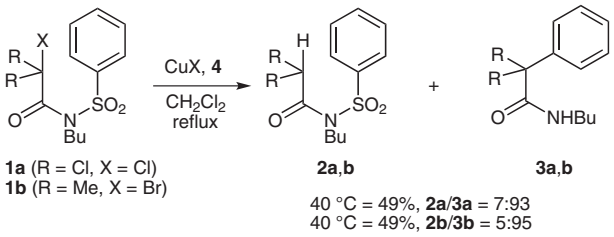
Received 8 October 2009

Dedicated to Prof. G. Pattenden on his 70th birthday.

Abstract: Reaction of *N*-butyl-*N*-(2-bromo-2-methylpropionyl)-arylsulfonamides with CuBr/tripyridylamine leads to amidyl radicals via 1,4-aryl migration with concomitant loss of SO_2, which can further undergo cyclisation to oxindoles or reduction to amides with the ratio dependent upon the temperature and solvent utilised.

Key words: copper, radical reactions, rearrangement, tandem reactions, sulfonamides

We recently reported that trichloroacetamide[1] **1a** and 2-bromo-2-methyl-propionamide[2] **1b** undergo reaction with copper(I) halides and pentamethyldiethylenetriamine **4** to furnish 2-aryl amides **3a**,**b** via 1,4-aryl migration. At reflux, minor amounts of competing halide reduction to give **2a**,**b** were also observed but levels only became signficant at room temperature (**2a/3a** = 61:39, **2b/3b** = 53:47, Scheme 1).[1,2] Aryl transfer from sulfonamides with loss of SO_2 during radical reactions is well established and a range of migration types including 1,4- and 1,5-aryl migrations have been described.[3] The majority of these published procedures involve reactions mediated by toxic organostannane reagents under high-dilution conditions.



Scheme 1 Reaction of amides **1a**,**b** with CuX–**4**

Conventional copper(I)-mediated atom-transfer radical cyclisations of haloacetamides have been thoroughly investigated and a range of ligands (e.g., **4**–**7**) have been reported to facilitate these types of transformations (Figure 1).[4–8] We previously screened ligands **4** and **7** in the 1,4-aryl transfer of trichloroacetamide **1a** and discovered that ligand **4** was optimal for production of **3a**.[1] In this paper we report the affect of ligand **7** in the 1,4-aryl transfer reaction of the related 2-bromo-2-methyl-propionamide **1b** at various temperatures and in various solvents (Table 1). We initially reacted compound **1b** with 1.1 equivalents of CuBr and 1.1 equivalents of ligand **7** at room temperature. The reaction was extremely slow due to the insolubility of the CuBr–**7** complex in both toluene (entry 3) and CH_2Cl_2 (entry 1), but when heated to solubilise the complex, two products were isolated, namely the 1,4-aryl rearrangement product **3b** and the oxindole **8b** (entries 2 and 4). The oxindole **8b** was unexpected, but its structure was unambiguously confirmed via the synthesis of an authentic sample and the lack of any sulfur content as determined by elemental analysis.[9]

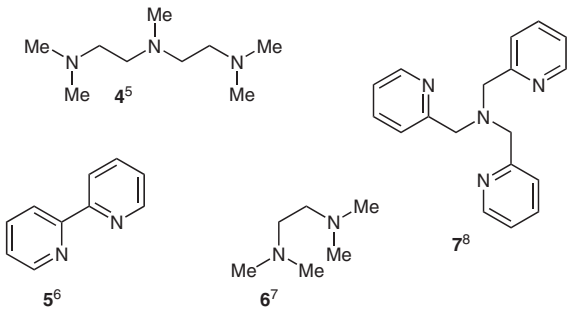
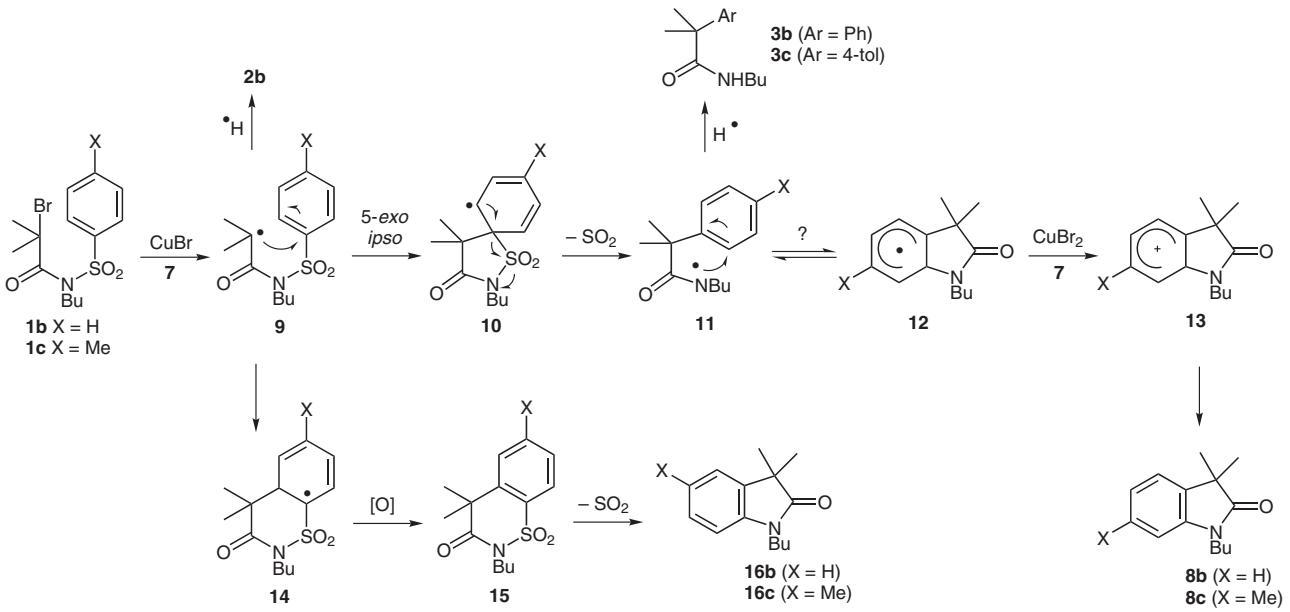


Figure 1 Common ligands used in copper-mediated ATRC reactions

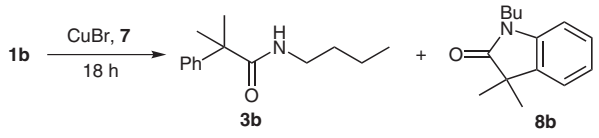
Contrary to the reaction of **1a** with CuBr–**7**[2] no reduction to **2b** was detected in the NMR spectrum of the crude material (entry 1). Mechanistically **3b** and **8b** (Scheme 2) are likely to be formed via a 5-*exo-ipso* substitution of radical **9** (X = H) to give spirocyclohexadienyl radical **10** which upon re-aromatisation and loss of SO_2 furnishes the amidyl radical **11** (X = H).[10,3h] Radical **11** is partioned between two competing reaction pathways (a bimolecular reduction to give **3b** or an intramolecular cyclisation to give **12**). Reduction of **11** furnishes the observed 1,4-aryl transfer product **3b**, while the oxindole **8b** may originate via radical cyclisation of the amidyl radical **11** (X = H) to give the cyclohexadienyl radical **12**. Oxidation of this radical **12**, mediated by the $CuBr_2$ formed in situ from the initial step **1b** → **9**, followed by elimination of a proton provides the observed oxindole product **8b**.[11,12] No six-membered cyclic sulfonamide **15** was isolated. This is in contrast to Bu_3SnH-mediated reactions of related sulfonamides where cyclic sulfonamide intermediates were detected.[3] Interestingly, the ratio of products seems to be

SYNLETT 2010, No. 4, pp 0610–0614
Advanced online publication: 22.12.2009
DOI: 10.1055/s-0029-1219151; Art ID: D28709ST



Scheme 2 Possible mechanism for the formation of oxindole **8b**

Table 1 Effect of Solvent and Temperature on the Reaction of **1a**

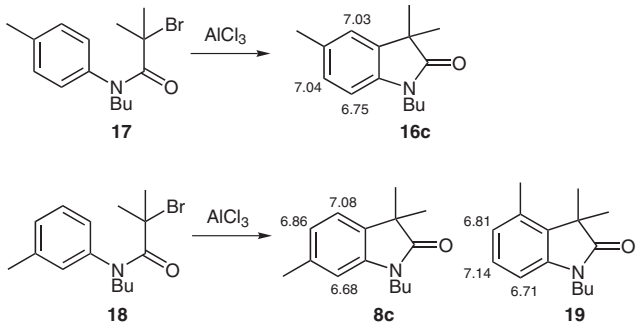


Entry	Solvent	Temp (°C)	Conv (%)	Mass balance (%)	Ratio **3b/8b**[a]
1	CH_2Cl_2	r.t.	33	65	1.0:0.0[b]
2	CH_2Cl_2	40	100	78	1.4:1.0
3	toluene	r.t.	0	100	–[c,d]
4	toluene	50	12	83	1.0:1.0
5	toluene	110	100	72	0.3:1.0
6	toluene	110	100	66	0.2:1.0[e]
7	THF	50	88	54	2.0:1.0
8	H_2O	50	100	51	2.0:1.0[f]
9	MeCN	50	100	74	1.0:0.0[g]

[a] Ratio determined by ^{1}H NMR (300 MHz) of the crude mixture. Reaction time 18 h.
[b] Reaction time = 168 h.
[c] Not measured due to low conversion.
[d] Reaction time = 96 h.
[e] Reaction time = 48 h.
[f] 5% of mass balance contained reduced product **2b**.
[g] Only 10% of **3b** was isolated. The rest of the mass balance (64%) was uncharacterised material.

solvent and temperature dependent (changing the solvent from CH_2Cl_2 to toluene and increasing the temperature leads to relatively more oxindole **8b**, compare entries 1 and 2 and entries 4 and 5). The use of THF marginally favoured the 1,4-aryl-transfer product **3b** but conversion was poorer than for the other solvents, while both H_2O and MeCN led to byproducts and consequently more complex reaction mixtures. Increasing the reaction time from 18 hours to 48 hours (compare entries 5 and 6) had little influence on the product ratio. Although we postulated that oxindole **8b** was likely formed via cyclisation of **11** (**11** → **12** → **13** → **8b**) we could not rule out its formation from extrusion of SO_2 from the undetected cyclic sulfonamide **15** (i.e., **15** → **16b** where **16b** = **8b**).[13] In order to probe this further we prepared the 4-tolyl derivative **1c**[2] and investigated its reaction with CuBr–**7** under two sets of conditions (CH_2Cl_2, 40 °C, 18 h and toluene, 110 °C, 24 h). By analogy to **1b** the expected products would be the 2-aryl amide **3c** and the 6-methyl oxindole **8c** (assuming pathway **11** → **12** → **13** → **8c**) or 5-methyl oxindole **16c** (assuming pathway **9** → **14** → **15** → **16c**). We also prepared authentic samples of both of these oxindoles **8c** and **16c** via an intramolecular Friedel–Crafts acylation of the corresponding amides **17** and **18** (Scheme 3) and key ^{1}H NMR and ^{13}C NMR data are presented.[14] As observed for compound **1b** the nature of the solvent and the temperature at which the reaction was carried out affected the ratio of products.[15] Thus, the amide **3c** was the major product when **1c** was heated at 40 °C in CH_2Cl_2 over 18 hours (**1c**/**8c** = 1.2:1.0, 55%) while the oxindole **8c** was the major product at 110 °C in toluene for 24 hours, (**1c**/**8c** = 0.6:1.0, 94%), this parallels the reactivity of **1b** (see entries 2 and 5, Table 1). Comparison of the spectral details of the oxindole produced with authentic samples of **8c** and **16c** unambiguously indicated that the product was 6-methyl oxindole **8c** providing further evidence for the proposed mechanistic pathway **10** → **8c**.

The generation of amidyl radicals by the loss of SO_2 from sulfonamides has recently been reported by Zard[16] and amidyl radical cyclisations are well known in the literature[17] with the majority of procedures involve 4-



Scheme 3 Synthesis of regioisomeric oxindoles **8c** and **16c** and representative ^{1}H NMR data (ppm)

exo[18] or 5-*exo*[19–24] cyclisations onto alkenes. Cyclisation of amidyl radicals directly into aromatic groups is not so well established and only reduction was reported for the structurally related amidyl radical **20**.[25]

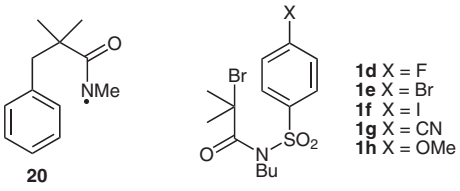
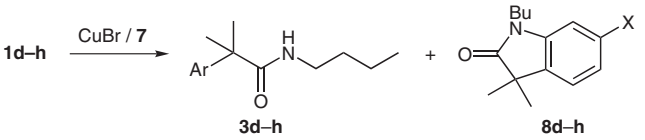


Figure 2 Structures of amidyl radical **20** and sulfonamides **1d–h**

We next briefly investigated the effect of changing the electronic nature of the *para* substituent (Figure 2). The synthesis of these substrates has been described previously.[2] Treating each substrate with 1 equivalent of CuBr–**7** in either CH_2Cl_2 or toluene led to both the amides **3d–h** and the oxindoles **8d–h** in varying ratios (Table 2). In all cases, the rates of reaction were faster than for the parent compound **1b**. The relative order of the rate of reaction (in CH_2Cl_2) was found to be **1b** = ca. **1c** < **1d** = ca. **1e** = ca. **1f** < **1g** = ca. **1h** indicating both electron-donating and -withdrawing groups accelerated the transformation. The intermediate cyclohexadienyl radical **10** will be stabilised by both electron-donating and electron-withdrawing substituents which should favour cyclisation and is reflected in this rate. The reactions carried out in toluene took longer to reach completion, and this may be reflected in the relative solubilities of CuBr–**7** in both solvents. As before, changing the conditions from CH_2Cl_2 (40 °C) to toluene (110 °C) increased the relative proportion of the oxindole **8** in the mixture (Table 2). In CH_2Cl_2, the main product is always the amide **3b–h** with the ratio of the two products **3b–h/8b–h** increasing from 1.2:1.0 to 4.0:1.0. The order of this increase being similar to that reflected in the relative rates of the reactions, **1c** = ca. **1b** = ca. **1d** < **1e** = ca. **1f** < **1g** = ca. **1h**. We previously reported that when **1b–d** are reacted with a different copper complex (CuBr–**4**) no oxindole **8b–d** is detected and **3b–d** is formed.[2] This indicates that the relative ratio of amide **3b**,**c** to oxindole **8b**,**c** is temperature, solvent, and ligand dependent. A difference in reactivity and selectivity has also been observed between between CuBr–**4** and CuBr–**7** in atom-transfer radical cyclisation reactions. In particular, radical reactions that use amine ligands (e.g. CuBr–**4** or CuBr–**6**), generally lead to greater reduction of intermediate radicals than those derived from pyridine ligands (e.g. CuBr–**5** or CuBr–**7**).[3b] The reason for this observation is not clear, but the source of the 'H' mediating the reduction was proposed to originate from the ligand (e.g.. **4** or **6**) itself.[3b] Thus, the rate of reduction of **11** is likely to be faster with CuBr–**4** than with CuBr–**7** explaining why no oxindole is formed with the former ligand. In addition, the redox potential of CuBr–**4** and CuBr–**7** complexes are sufficiently different[26] that the rate of the oxidation step **12** → **13** is also likely to be ligand dependent.

In conclusion, we have shown that reaction of *N*-butyl-*N*-(2-bromo-2-methylpropionyl)arylsulfonamides **1b–h** with CuBr–**7** leads to amidyl radicals via 1,4-aryl migration with concomitant loss of SO_2 which can further undergo cyclisation to oxindoles **8b–h** or reduction to amides **3b–h** with the ratio dependent upon the solvent and temperature employed.

Table 2 Effect of Substituent X on the Reactions of **1d–h**



Compd	Solvent	Temp (°C)	Time (h)[a]	Yield (%)[b]	Ratio of **3d–h**/**8d–h**[c]
1d	CH_2Cl_2	40	7	59	1.4:1.0
1d	toluene	110	18	45	0.5:1.0
1e	CH_2Cl_2	40	7	66	2.4:1.0
1f	CH_2Cl_2	40	8	80	2.7:1.0
1g	CH_2Cl_2	40	4	53	4.0:1.0
1g	toluene	110	18	66	1.3:1.0
1h	CH_2Cl_2	40	18[d]	73	4.0:1.0
1h	toluene	80	18[e]	45	1.0:1.0[f]

[a] Time taken to reach 100% conversion.
[b] Combined yield of **3d–h** and **8d–h**.
[c] Ratio determined by ^{1}H NMR (300 MHz) of the crude mixture.
[d] The reaction had proceeded to 100% conversion in 3 h.
[e] Under indentical conditions the reaction of **1c** proceeded to 56% conversion.
[f] A minor uncharacterised product (5%) was also isolated.

Acknowledgment

We acknowledge the EPSRC for DTA studentships (N.P.M.) and for a project studentship EP/F016573 (H.P.).

References and Notes

(1) Clark, A. J.; Coles, S. R.; Collis, A.; Debure, T.; Guy, C.; Murphy, N. P.; Wilson, P. *Tetrahedron Lett.* **2009**, *50*, 5609.

(2) Clark, A. J.; Coles, S. R.; Collis, A.; Fullaway, D. R.; Murphy, N. P.; Wilson, P. *Tetrahedron Lett.* **2009**, *50*, 6311.
(3) (a) Loven, R.; Speckamp, W. N. *Tetrahedron Lett.* **1972**, *13*, 1567. (b) Köhler, J. J.; Speckamp, W. N. *Tetrahedron Lett.* **1977**, *18*, 631. (c) Köhler, J. J.; Speckamp, W. N. *Tetrahedron Lett.* **1977**, *18*, 635. (d) Köhler, J. J.; Speckamp, W. N. *J. Chem. Soc., Chem. Commun.* **1978**, 166. (e) Köhler, J. J.; Speckamp, W. N. *J. Chem. Soc., Chem. Commun.* **1980**, 142. (f) Clive, D. L. J.; Boivin, T. L. B. *J. Org. Chem.* **1989**, *54*, 1997. (g) Motherwell, W. B.; Pennell, A. M. K. *J. Chem. Soc., Chem. Commun.* **1991**, 877. (h) da Mata, M. L. E. N.; Motherwell, W. B.; Ujjainwalla, F. *Tetrahedron Lett.* **1997**, *38*, 137. (i) da Mata, M. L. E. N.; Motherwell, W. B.; Ujjainwalla, F. *Tetrahedron Lett.* **1997**, *38*, 141. (j) Bonfand, E.; Forsland, L.; Motherwell, W. B.; Vázquez, S. *Synlett* **2000**, 475. (k) Studer, A.; Boassart, M. *Tetrahedron* **2001**, *57*, 9649. (l) Bossart, M.; Fässler, R.; Schoenberger, J.; Studer, A. *Eur. J. Org. Chem.* **2002**, 2742. (m) Gheorghe, A.; Quiclet-Sire, B.; Vila, X.; Zard, S. Z. *Org. Lett.* **2005**, *7*, 1653.
(4) Clark, A. J. *Chem. Soc. Rev.* **2002**, *31*, 1.
(5) (a) Clark, A. J.; Filik, R. P.; Thomas, G. H. *Tetrahedron Lett.* **1999**, *40*, 4885. (b) Clark, A. J.; De Campo, F.; Deeth, R. J.; Filik, R. P.; Gatard, S.; Hunt, N. A.; Lastécouères, D.; Thomas, G. H.; Verlac, J.-B.; Wongtap, H. *J. Chem. Soc., Perkin Trans. 1* **2000**, 671. (c) Clark, A. J.; Geden, J. V.; Thom, S.; Wilson, P. *J. Org. Chem.* **2006**, *71*, 1471.
(6) (a) Nagashima, H.; Ozaki, N.; Ishii, M.; Seki, K.; Washiyama, M.; Itoh, K. *J. Org. Chem.* **1993**, *58*, 464. (b) Iwamatsu, S.; Matsubara, K.; Nagashima, H. *J. Org. Chem.* **1999**, *64*, 9625. (c) Nagashima, H.; Isono, Y.; Iwamatsu, S. *J. Org. Chem.* **2001**, *66*, 315.
(7) (a) Ghelfi, F.; Pattarozzi, M.; Roncaglia, F.; Parsons, A. F.; Felluga, F.; Pagnoni, U. M.; Valentin, E.; Mucci, A.; Bellesia, F. *Synthesis* **2008**, 3131. (b) Ghelfi, F.; Stevens, C. V.; Laureyn, I.; Van Meenen, E.; Rogge, T. M.; De Buyck, L.; Nikitin, K. V.; Grandi, R.; Libertini, E.; Pagnoni, U. M.; Schenetti, L. *Synthesis* **2007**, 1882. (c) Bellesia, F.; Daniel, C.; De Buyck, L.; Galeazzi, R.; Ghelfi, F.; Mucci, A.; Orean, M.; Pagnoni, U. M.; Parsons, A. F.; Roncaglia, F. *Tetrahedron* **2006**, *62*, 746. (d) Bryans, J. S.; Chessum, N. E. A.; Huther, N.; Parsons, A. F.; Ghelfi, F. *Tetrahedron* **2003**, *59*, 6221. (e) Cagnoli, R.; Ghelfi, F.; Pagnoni, U. M.; Parsons, A. F.; Schenetti, L. *Tetrahedron* **2003**, *59*, 9951. (f) Ghelfi, F.; Parsons, A. F. *J. Org. Chem.* **2000**, *65*, 6249. (g) Ghelfi, F.; Bellesia, F.; Forti, L.; Ghirardini, G.; Grandi, R.; Libertini, E.; Montemaggi, M. C.; Pagnoni, U. M.; Pinetti, A.; De Buyck, L.; Parsons, A. F. *Tetrahedron* **1999**, *55*, 5839. (h) Benedetti, M.; Forti, L.; Ghelfi, F.; Pagnoni, U. M.; Ronzoni, R. *Tetrahedron* **1997**, *41*, 14031.
(8) (a) Clark, A. J.; Dell, C. P.; McDonagh, J. P. *C. R. Acad. Sci.. Ser. IIC* **2001**, *4*, 575. (b) Clark, A. J.; Battle, G. M.; Bridge, A. *Tetrahedron Lett.* **2001**, *42*, 1999. (c) Clark, A. J.; Battle, G. M.; Bridge, A. *Tetrahedron Lett.* **2001**, *42*, 2003. (d) Clark, A. J.; Battle, G. M.; Bridge, A. *Tetrahedron Lett.* **2001**, *42*, 4409. (e) Clark, A. J.; Geden, J. V.; Thom, S.; Wilson, P. *J. Org. Chem.* **2006**, *71*, 1471. (f) Clark, A. J.; Geden, J. V.; Thom, S.; Wilson, P. *J. Org. Chem.* **2007**, *72*, 5923. (g) Clark, A. J.; Wilson, P. *Tetrahedron Lett.* **2008**, *49*, 4848.
(9) Baillet, G.; Campredon, M.; Guglielmetti, R.; Giusti, G.; Aubert, C. *J. Photochem. Photobiol.. A* **1994**, *83*, 147.
(10) Montermini, F.; Lacote, E.; Malacria, M. *Org. Lett.* **2004**, *6*, 921.
(11) For a review on aromatic homolytic substitution, see: Bowman, W. R.; Storey, J. M. D. *Chem. Soc. Rev.* **2007**, *36*, 1803.
(12) Clark, A. J.; Filik, R. P.; Peacock, J. L.; Thomas, G. H. *Synlett* **1999**, 441.
(13) Godfrey, C. R. A.; Hegarty, P.; Motherwell, W. B.; Ujjainwalla, F. *Tetrahedron Lett.* **1998**, *39*, 723.
(14) 2-Bromo-*N*-butyl-2-methyl-*N*-4-tolylpropanamide (1.50 g, 4.8 mmol) was added to anhyd $AlCl_3$ (1.62 g, 12.1 mmol) under a stream of nitrogen. The mixture was heated at 50 °C for 10 min and then maintained at 160 °C for 1 h. The mixture was washed with H_2O (5 × 50 mL) and extracted with Et_2O, dried over $MgSO_4$, and evaporated to give **16c** (0.45 g, 41%) after chromatography (PE–EtOAc, 10:1); R_f = 0.40 (PE–EtOAc, 10:1). IR: ν_{max} = 2962, 2929, 2865, 1705, 1619, 1599, 1493, 1381, 1351, 1192 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.04 (1 H, d, *J* = 8.0 Hz), 7.03 (1 H, s), 6.75 (1 H, d, *J* = 8.0 Hz), 3.69 (2 H, t, *J* = 8.0 Hz), 2.34 (3 H, s), 1.65 (2 H, quin, *J* = 8.0 Hz), 1.35 (2 H, sext, *J* = 8.0 Hz), 1.35 (3 H, s), 0.94 (3 H, t, *J* = 8.0 Hz). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 181.3, 139.7, 136.1, 131.7, 127.7, 123.3, 108.1, 44.1, 39.6, 29.5, 24.5, 21.1, 20.1, 13.8. ESI-HRMS: *m/z* calcd for $Na^+C_{15}H_{21}NO$: 254.1515; found [Na^+]: 254.1522.
Data for the Mixture of 8c and 19
IR: ν_{max} = 2963, 2931, 2871, 1707, 1606, 1462, 1383, 1343, 1223 cm^{-1}. ESI-HRMS: *m/z* calcd for $Na^+C_{15}H_{21}NO$: 254.1515; found [Na^+]: 254.1519.
Data for 19
^1H NMR (400 MHz, $CDCl_3$): δ = 7.14 (1 H, t, *J* = 8.0 Hz), 6.81 (1 H, d, *J* = 8.0 Hz), 6.71 (1 H, d, *J* = 8.0 Hz), 3.70 (2 H, t, *J* = 8.0 Hz), 2.40 (3 H, s), 1.65 (2 H, quin, *J* = 8.0 Hz), 1.44 (3 H, s), 1.37 (2 H, sext, *J* = 8.0 Hz), 0.94 (3 H, t, *J* = 8.0 Hz). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 181.3, 142.3, 134.2, 132.8, 127.4, 124.7, 106.1, 44.9, 39.6, 29.5, 22.4, 20.1, 18.2, 13.8.
Data for 8c
^1H NMR (400 MHz, $CDCl_3$): δ = 7.08 (1 H, d, *J* = 8.0 Hz), 6.86 (1 H, d, *J* = 8.0 Hz), 6.68 (1 H, s), 3.69 (2 H, t, *J* = 8.0 Hz), 2.38 (3 H, s), 1.65 (2 H, quin, *J* = 8.0 Hz), 1.37 (2 H, sext, *J* = 8.0 Hz), 1.34 (3 H, s), 0.95 (3 H, t, *J* = 8.0 Hz). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 181.3, 142.3, 137.6, 133.2, 122.6, 122.1, 109.2, 43.8, 39.5, 29.6, 24.6, 21.8, 20.1, 13.8.
(15) A typical procedure is illustrated for reaction of **1b** with CuBr (entry 2, Table 1). Substrate **1b** (0.3 mmol) was added to dry CH_2Cl_2 (2 mL), and CuBr (0.33 mmol) and tripyridylamine (0.33 mmol) were added. The reaction mixture was heated at 40 °C for 18 h. Upon cooling, the crude mixture was passed through a small silica plug (eluting with EtOAc, 20 mL to remove copper residues). After evaporation of the solvent and chromatography (PE–EtOAc, 8:1) a mixture of amide **3b** and oxindole **8b** were isolated in the ratio of 1.4:1.0, combined yield 78%. Spectroscopic data for **3b** were identical to an authentic sample prepared previously[2,9] and data for **8b** were identical to that reported above.[14]
(16) Moutrille, C.; Zard, S. Z. *Chem. Commun.* **2004**, 1848.
(17) For reviews on nitrogen-centered radicals, see: (a) Zard, S. Z. *Synlett* **1996**, 1148. (b) Esker, J. L.; Newcomb, M. *Adv. Heterocycl. Chem.* **1993**, *58*, 1.
(18) Clark, A. J.; Peacock, J. L. *Tetrahedron Lett.* **1998**, *39*, 1265.
(19) (a) Newcomb, M.; Esker, J. L. *Tetrahedron Lett.* **1991**, *32*, 1035. (b) Esker, J. L.; Newcomb, M. *J. Org. Chem.* **1993**, *58*, 4933. (c) Horner, J. H.; Musa, O. M.; Bouvier, A.; Newcomb, M. *J. Am. Chem. Soc.* **1998**, *120*, 7738.

(20) (a) Clark, A. J.; Peacock, J. L. *Tetrahedron Lett.* **1998**, *39*, 6029. (b) Clark, A. J.; Deeth, R. J.; Samuel, C. J.; Wongtap, H. L. *Synlett* **1999**, 444.
(21) (a) Lin, X.; Stien, D.; Weinreb, S. M. *Tetrahedron Lett.* **2000**, *41*, 2333. (b) Artman, G. D.; Stien, D.; Weinreb, S. M. *Synthesis* **2002**, 2057.
(22) (a) Callier, A.-C.; Quiclet-Sire, B.; Zard, S. Z. *Tetrahedron Lett.* **1994**, *35*, 6109. (b) Callier-Dubalanchet, A.-C.; Quiclet-Sire, B.; Zard, S. Z. *Tetrahedron Lett.* **1995**, *36*, 8791. (c) Sharp, L. A.; Zard, S. Z. *Org. Lett.* **2006**, *8*, 831.
(23) (a) Tang, Y.; Li, C. *Org. Lett.* **2004**, *6*, 3229. (b) Chen, Q.; Shen, M.; Tang, Y.; Li, C. Z. *Org. Lett.* **2005**, *7*, 1625. (c) Lu, H. J.; Chen, Q.; Li, C. Z. *J. Org. Chem.* **2007**, *72*, 2564. (d) Yuan, X. T.; Liu, K.; Li, C. Z. *J. Org. Chem.* **2008**, *73*, 6166.
(24) Yu, Y.-Y.; Fu, Y.; Xie, M.; Liu, L.; Guo, Q.-X. *J. Org. Chem.* **2007**, *72*, 8025.
(25) Rey, V.; Pierini, A. B.; Peňéňory, A. B. *J. Org. Chem.* **2009**, *74*, 1223.
(26) Qiu, J.; Matyjaszewski, K.; Thouin, L.; Amatore, C. *Macromol. Chem. Phys.* **2000**, *201*, 1625.