JOC The Journal of Organic Chemistry

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Copper-Catalyzed Petasis-Type Reaction: A General Route to α-Substituted Amides From Imines, Acid Chlorides, and Organoboron Reagents

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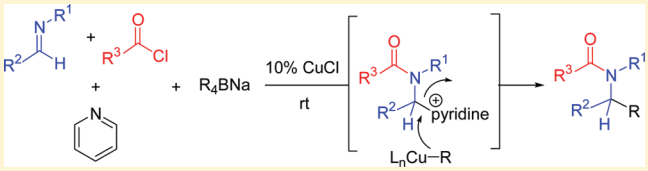
Supporting Information

ABSTRACT: A copper-catalyzed Petasis-type reaction of imines, acid chlorides, and organoboranes to form α-substituted amides is described. This reaction does not require the use of activated imines or the transfer of special units from the organoboranes and represent a useful generalization of the Petasis reaction.



Because of their relevance in pharmaceuticals and other bioactive compounds, there is significant interest in the synthesis of α-substituted amines and amides.[1] One straightforward strategy is the nucleophilic addition of organometallic reagents to imines.[2] However, this approach can be limited by the poor electrophilicity of the C═N double bond and the instability of some imines toward reactive organometallic reagents (e.g., organolithium and organomagnesium compounds). Because of their low toxicity, stability to air and water, and functional group tolerance, organoboron reagents have become wildly used in organic synthesis.[3] This includes in carbon−carbon bond-forming reactions with imines, via either transition-metal-catalyzed[4] or noncatalytic pathways.[5] Transition-metal-mediated variants of this reaction often employ rhodium or palladium catalysts and can be very effective, though they do generally require activated imines bearing electron-withdrawing groups on the nitrogen, such as *N*-sulfonyl, *N*-diphenylphosphinoyl, and *N*-sulfinyl imines.[4] Alternatively, the non-metal-catalyzed couplings with organoboranes often involve the use of in situ generated iminium ions, i.e., the Petasis reaction.[5] These typically require directing groups at the α- or β-position to the iminium salt carbon (e.g., α-keto acids, α-hydroxy aldehydes, and salicylaldehydes). While there are exceptions to the latter,[6] particularly with less sterically hindered aldehydes (e.g., paraformaldehyde) or reactive organoboranes (e.g., allylic boranes or 2-fufurylboranes), this can limit the scope of α-substituted amines available via this route.

Considering the availability and stability of organoboron reagents, we became interested in the potential development of a general approach to employ these reagents in imine addition. We have recently demonstrated that palladium or copper complexes can catalyze the cross-coupling like reaction between in situ generated *N*-acyl iminium salts and organo-tin or -indium reagents.[7,8] Similarly, Doyle has reported that heterocyclic ethoxy-substituted carbamates can undergo a nickel-catalyzed Petasis-type coupling with aryl-boron reagents,[9] while Li has found that rhodium complexes can catalyze aryl-borane reactions with α-amido sulfones.[10] In addition, various research groups have found that copper salts can catalyze the addition of organometallic reagents to in situ generated iminium salts, in reactions that presumably proceed via the formation of organocopper intermediates from transmetalation.[11] We show herein how copper catalysis and the correct organoboron reagent can provide a novel method to assemble α-substituted amides from imines, acid chlorides, and borates. Notably, this reaction does not require activated or specialized imines and proceeds with a variety of organoboron reagents.

Our initial studies involved the CuCl-catalyzed reaction of the unactivated imine **1** with various phenyl-substituted organoboranes. As can be seen in Table 1, no amide product is observed either with or without acid chloride (entries 1, 2), nor in the presence of known organoborane activators (K_3PO_4, F^-, entries 3, 4). Similar results were observed with other phenyl-substituted organoboranes (entries 5, 6). Considering the cationic charge on the in situ generated iminium salts (vide infra), we postulated that negatively charged boron reagents might be better suited for this reaction, through initial ion pairing to the iminium unit. Indeed, the use of $Na^+BPh_4^-$ does result in the formation of trace amounts of **2a** (11%, entry 8), along with significant decomposition. A similar decomposition is observed without copper catalysts present (though without **2a** formation) and presumably arises from the generation of an unstable, uncoordinated *N*-acyl iminium cation with BPh_4^- as the counterion.[12]

It has been postulated in copper-catalyzed cross-coupling reactions that transmetalation of organic units from main group elements to copper(I) salts is reversible and can be inhibited by the buildup of the organometallic-halide byproduct as the reaction proceeds.[13] In our case, this byproduct is BPh_3. This product could in principle be trapped by Lewis bases. In addition, Lewis bases could coordinate to the *N*-acyl iminium salt, thereby lowering its background decomposition with BPh_4^-. As shown in Table 2, the addition of a catalytic amount of

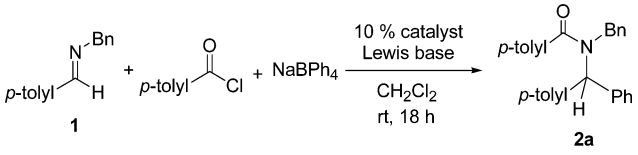
Received: November 25, 2011
Published: January 17, 2012

Table 1. Copper-Catalyzed Reaction of Imines and Organoboranes[a]

Entry	Organoborane	Additive	Yield **2a**
1		-	-
2[b]	"	-	-
3	"	K_3PO_4	-
4	"	F^-	-
5	$(MeO)_2B$-Ph	F^-	-
6	$(HO)_2B$-Ph	F^-	-
7	$K^+F_3BPh^-$	-	-
8	$Na^+BPh_4^-$	-	11%
9[c]	$Na^+BPh_4^-$	-	-

[a] *p*-tolyl(H)=NBn (41.8 mg, 0.20 mmol), *p*-toluoyl chloride (34 mg, 0.22 mmol), CuCl (2.0 mg, 0.02 mmol), organoborane (0.20 mmol), additive (0.30 mmol), CH_2Cl_2, rt, 18 h. [b] Without *p*-toluoyl chloride. [c] No CuCl.

Table 2. Reaction Optimization with Lewis Base Additives[a]



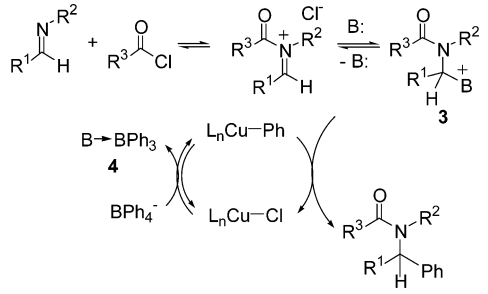
entry	Catalyst	Lewis Base	Yield %
1	CuCl	 (10%)	14
2	CuCl		83
3	$CuPF_6$		86
4	CuI		83
5[b]	CuCl		80
6	Pd_2dba_3		10
7[c]	CuCl	PPh_3	11
8	CuCl		43
9	CuCl	$P(n\text{-}Bu)_3$	-

[a] *p*-tolyl(H)=NBn (41.8 mg, 0.20 mmol), *p*-toluoyl chloride (34 mg, 0.22 mmol), $NaBPh_4$ (68.4 mg, 0.20 mmol), catalyst (0.02 mmol), and Lewis base (0.20 mmol), 2 mL CH_2Cl_2, rt, 18 h, yields determined by ^{1}H NMR. [b] 30 min, rt. [c] 60 °C.

pyridine base (10 mol %) increases the yield of **2a** to 14%, while the use of stoichiometric pyridine leads to near quantitative **2a** formation (83%, entry 2). This coupling is extremely rapid and proceeds to completion within 30 min at ambient temperature (entry 5). DMAP is also effective as the Lewis base additive (entry 8), while the more electron-rich phosphines either slow (PPh_3, entry 7) or inhibit (PBu_3, entry 9) catalysis.

The role of Lewis bases in this transformation can be probed by monitoring the copper-catalyzed reaction by ^{1}H NMR spectroscopy. This shows the immediate formation of a pyridine-containing intermediate prior to the addition of the copper catalyst.[14] This intermediate can be independently generated via the addition of pyridine to the *N*-acyl iminium salt and has been characterized as the pyridinium salt **3** (Scheme 1; B = pyridine).[15] The formation of **3** provides a rationale for the slower coupling reaction with DMAP relative to pyridine or inhibition with phosphines, since these more Lewis basic units presumably undergo slower displacement by the in situ formed organocopper complex to form the product.

Scheme 1. Proposed Mechanism of the Copper-Catalyzed Coupling



Compound **3** appears to be a viable intermediate in the catalytic reaction. Warming of the solution of **3** in the presence of the copper catalyst and $NaBPh_4$ leads to its slow disappearance together with the formation of amide **2a**. In addition to **2a**, a new organoboron product is observed in similar yield to **2a**: the pyridine-BPh_3 adduct **4**.

A useful feature of this catalytic coupling is that it does not require the use of specifically substituted imines or organoboranes. As such, it is easily diversified to assemble a range of α-substituted amides. For example, a number of simple imines can be used in this reaction. This includes *N*-benzyl, -aryl, and -alkyl imines, as well as imines derived from aryl- or heteroaryl-aldehydes (Table 3). Similarly, aryl-, alkyl-, and heteroaryl-acid chlorides provide amides in good yield (**2g**−**i**). The borate unit can also be easily tuned. In addition to simple phenyl-substituted borates, functionalized aryl- (**2b**, **2c**), heteroaryl- (**2d**), and even alkyl groups can be transferred to imines with good yields at room temperature (**2f**, **2 g**). α,β-unsaturated imines can also be employed in this reaction, leading to the 1,2-addition product **2k**.

The formation of the Lewis base coordinated intermediate **3** also allows the use of less stabilized imines in this chemistry. For example, due to their sensitivity to base, enolizable imines can be more challenging substrates for coupling with organometallic reagents, and their corresponding *N*-acyl iminium salts are very prone to enamide formation. The latter has precluded their use in similar copper-catalyzed coupling reactions with other organometallic reagents.[16] However, because of the low basicity of organoborates and the generation of a stabilized pyridinium salts **3**, these imines can also be employed in this copper-catalyzed reaction, affording **2l** in good yield (Scheme 2).

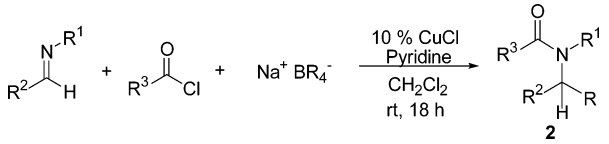
In conclusion, we have developed a copper-catalyzed multicomponent synthesis of α-substituted amides from imines, acid chlorides, and organoborane reagents. Considering the simplicity of the catalyst, the generality of the reaction, and the stability of these reagents, this provides a straightforward route to construct α-substituted amides. This approach does not require the use of activated imines or the transfer of special units from the organoboranes. As such, it represents a useful generalization of Petasis-type coupling reactions of in situ generated iminium salts with organoboranes.

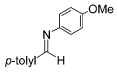
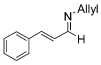
EXPERIMENTAL SECTION

General Procedures. Unless otherwise noted, all manipulations were performed under an inert atmosphere dry glovebox or by using standard Schlenk or vacuum line techniques. Imines were prepared using literature procedures.[17] $R_4B^-Na^+$ were synthesized from the corresponding Grignard reagent and sodium tetrafluoroborate.[18] Acetonitrile and CH_2Cl_2 were distilled from CaH_2 under nitrogen.

dx.doi.org/10.1021/jo202339v | J. Org. Chem. 2012, 77, 2013−2017

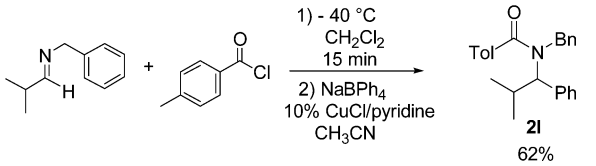
Table 3. Diversity of Copper-Catalyzed Multicomponent Coupling of Imines, Acid Chlorides, and Organoboron Reagents



Pdt	Imine	R^3	R	Yield %
2b		Ph		74
2c		Ph		90
2d[b]				80
2e		Ph		71
2f		Ph	-CH_2Ph	71
2g		*p*-tolyl	Et	74
2h			Ph	70
2i			Ph	57
2j			Ph	83
2k		*p*-tolyl	Ph	62

[a]Imine (0.20 mmol), acid chloride (0.22 mmol), organoborane (0.20 mmol), CuCl (2.0 mg, 0.020 mmol), pyridine (15.8 mg, 0.20 mmol), 2 mL CH_2Cl_2, rt, 18 h. [b]With KB(2-thiophenyl)$_4$.

Scheme 2. Coupling Reaction with Enolizable Imine



Deuterated solvents were dried as their protonated analogues but were transferred under vacuum from the drying agent and stored over 3 Å molecular sieves. ^{1}H, ^{13}C, and ^{11}B NMR spectra were recorded on 300, 400, or 500 MHz spectrometers.

Typical Synthesis of α-Substituted Amides. *p*-Tolyl(H)═NBn (41.1 mg, 0.20 mmol) and *p*-toluoyl chloride (34 mg, 0.22 mmol) were dissolved in CH_2Cl_2 (0.5 mL), after 30 min pyridine (15.8 mg, 0.20 mmol) was added with 0.5 mL of CH_2Cl_2, and the solution was transferred to a vial with $NaBPh_4$ (68.4 mg, 0.20 mmol). CuCl (2.0 mg, 0.020 mmol) in 0.5 mL of CH_2Cl_2 was added, and the reaction solution was stirred at room temperature for 18 h. The solvent was removed in vacuo, and the resulting product was isolated by chromatography on silica gel 60 using hexanes/ethyl acetate as eluent, affording the **2a** in 83% yield.

Synthesis of 2l. Isopropyl(H)═NBn (32.2 mg, 0.20 mmol) was dissolved in 0.5 mL of CH_2Cl_2 in a Schlenk flask and cooled to −40 °C. *p*-Toluoyl chloride (37.0 mg, 0.24 mmol) in 0.5 mL of CH_2Cl_2 was added via syringe over 5 min. After15 min of stirring at −40 °C, pyridine (15.8 mg, 0.20 mmol), $NaBPh_4$ (68.4 mg, 0.20 mmol), and CuCl (2.0 mg, 0.020 mmol) in 1 mL of CH_3CN was added over 5 min. The reaction warmed to ambient temperature overnight, the solvent removed was in vacuo, and the resulting product was isolated by chromatography on silica gel 60 using hexanes/ethyl acetate as eluent, affording the amide **2l** in 62% yield.

In Situ Formation of 3. *p*-Tolyl(H)═NBn (41.8 mg, 0.20 mmol) and benzoyl chloride (39.3 mg, 0.28 mmol) were mixed neat. After 15 min, pyridine (31.6 mg, 0.40 mmol) was added, and the neat mixture was allowed to stand for 30 min. Pentane (3 mL) was added, and the precipitate was collected in 50% yield. NMR data shows this precipitate is **3** in rapid equilibrium with small amounts of free pyridine, acid chloride, and *N*-acyl iminium salt. As such, its structure was assigned by in situ by NMR spectroscopy. ^{1}H NMR (500 MHz, $CDCl_3$, −10 °C): δ 9.77 (d, *J* = 6.0 Hz, 2H), 8.60 (s, 1H), 8.34 (t, *J* = 7.5 Hz, 1H), 7.88 (t, *J* = 7.0 Hz, 2H), 7.68 (d, *J* = 7.5 Hz, 2H), 7.38−7.43 (m, 3H), 7.07 (d, *J* = 8.0 Hz, 2H), 6.91 (m, 7H), 5.42 (d, *J* = 15.5 Hz, 1H), 5.24 (d, *J* = 16.0 Hz, 1H), 2.19 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$, −10 °C): δ 174.1, 145.9, 144.6, 140.0, 136.2, 134.1, 131.5, 129.6, 129.0, 128.9, 128.5, 128.0, 127.9$_8$, 127.8, 127.7, 127.5, 84.7, 55.2, 21.3.

Generation of Pyridine:BPh_3 (4). Pyridine (31.6 mg, 0.40 mmol) and BPh_3 (96.8 mg, 0.40 mmol) were dissolved in 2 mL of $CHCl_3$. After 1 h of stirring at 65 °C, an amorphous white solid was formed, which was collected and washed with CH_3CN. The complex **4** was obtained in 30% yield. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.59 (d, *J* = 5.5 Hz, 2H), 8.03 (t, *J* = 7.5 Hz, 1H), 7.54 (t, *J* = 7.0 Hz, 2H), 7.16−7.26 (m, 15H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 151.9, 148.1, 140.3, 134.7, 127.1, 125.3, 124.9. ^{11}B (160 MHz, $CDCl_3$): δ 4.4.

Spectroscopic Data for α-Substituted Amides. *N-Benzyl-4-methyl-N-(phenyl(p-tolyl)methyl)benzamide (**2a**).* Isolated yield 83%. White amorphous solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.85−8.00 (m, 18H), 6.68 (br, 1H), 4.76 (s, 2H), 2.38 (s, 3H), 2.36 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$, 50 °C): δ 173.4, 144.3, 139.6, 139.4, 138.2, 137.3, 136.3, 134.1, 130.2, 129.0, 128.9, 128.3, 127.7, 127.5, 127.1, 126.5, 126.1, 65.9, 48.5, 21.3, 20.9. IR: ν_{max} (KBr) 1639 (C═O). HRMS: calcd for $C_{29}H_{27}ONNa^+$ 428.1979, found 428.1981.

*N-Ethyl-N-(thiophen-2-yl(p-tolyl)methyl)benzamide (**2b**).* Isolated yield 74%. Brown solid, mp 95−96 °C. ^{1}H NMR (500 MHz, $CDCl_3$, 55 °C): δ 7.38−7.46 (m, 5H), 7.29 (dd, *J* = 1.5, 5.5 Hz, 1H), 7.15−7.20 (m, 4H), 7.00 (dd, *J* = 3.5, 5 Hz, 1H), 6.89−6.90 (m, 1H), 6.57 (br, 1H) 3.53 (q, *J* = 6.5 Hz, 2H), 2.36 (s, 3H), 0.80 (br, 3H). ^{13}C NMR (125 MHz, $CDCl_3$, 55 °C): δ 171.8, 143.7, 137.8, 137.2, 136.2, 129.3, 129.1, 128.4, 128.2, 127.0, 126.7, 126.3, 125.2, 61.0, 40.1, 20.9, 13.9. IR: ν_{max} (KBr) 1618 (C═O). HRMS: calcd for $C_{21}H_{21}ONSNa^+$ 358.1236, found 358.1238.

*N-Benzyl-N-((4-fluorophenyl)(p-tolyl)methyl)benzamide (**2c**).* Product was purified by silica gel chromatograph using 5:95 ethyl acetate/toluene mixture as eluent, isolated yield 90%. White solid, mp 88−90 °C. ^{1}H NMR (300 MHz, CD_3CN): δ 6.90−7.42 (m, 18H), 6.42 (br, 1H) 4.94 (d, *J* = 11.4 Hz, 1H), 4.71 (d, *J* = 11.4 Hz, 1H), 2.38 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 173.1, 162.1 (d, $^1J_{C-F}$ = 245.6 Hz), 137.9, 137.6, 136.8, 135.9, 135.1 (d, $^4J_{C-F}$ = 2.7 Hz), 130.7 (d, $^3J_{C-F}$ = 6.8 Hz), 129.5, 129.3, 128.6, 128.5, 127.8, 127.0, 126.4, 126.3, 115.2 (d, $^2J_{C-F}$ = 21.3 Hz), 65.6, 47.4, 21.1. IR: ν_{max} (KBr) 1638 (C═O). HRMS: calcd for $C_{28}H_{24}ONFNa^+$ 432.1732, found 432.1734.

*N-Benzyl-N-(thiophen-2-yl(p-tolyl)methyl)thiophene-2-carboxamide (**2d**).* Isolated yield 80%. Light yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.98−7.44 (m, 16H), 4.90 (dd, 2H), 2.39 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 166.1, 143.1, 138.2, 138.1, 138.0, 136.0, 129.7, 129.5, 129.0, 128.7, 128.3, 128.1, 127.2, 127.1, 127.0, 126.8, 126.0, 61.8, 50.4, 21.8. IR: ν_{max} (KBr) 1629 (C═O). HRMS: calcd for $C_{24}H_{21}ONS_2Na^+$ 426.0955, found 426.0957.

*N-Methyl-N-(naphthalen-2-yl(p-tolyl)methyl)benzamide (**2e**).* Product was purified by silica gel chromatograph using 5:95 ethyl acetate/toluene mixture as eluent, isolated yield 71%. Clear oil. ^{1}H NMR (500 MHz, CD_3CN, 70 °C): δ 7.86−7.94 (m, 3H), 7.75 (s, 1H), 7.52−7.56 (m, 2H), 7.42−7.48 (m, 5H), 7.33 (d, *J* = 8 Hz, 1H), 7.25 (d, *J* = 8 Hz, 2H), 7.17 (d, *J* = 7.5 Hz, 2H), 6.80 (br, 1H), 2.84 (s, 3H), 2.40 (s, 3H). ^{13}C NMR (125 MHz, CD_3CN, 70 °C): δ 171.8, 137.5, 137.3, 137.1, 136.2, 133.4, 132.8, 129.3, 129.2, 128.8, 128.4, 128.0, 127.9, 127.5, 127.1, 126.6, 126.5, 126.3, 126.2, 63.6, 32.2, 20.0. IR: ν_{max} (KBr) 1628 (C═O). HRMS: calcd for $C_{26}H_{24}ON^+$ 366.1852, found 366.1866.

*N-Benzyl-N-(2-phenyl-1-p-tolylethyl)benzamide (**2f**).* Isolated yield 71%. White solid, mp 68−70 °C. ^{1}H NMR (400 MHz,

dx.doi.org/10.1021/jo202339v | J. Org. Chem. 2012, 77, 2013−2017

CD_3CN, 80 °C): δ 6.88−7.49 (m, 19H), 5.52 (br, 1H), 4.62 (d, J = 13.5 Hz, 1H), 4.53 (d, J = 13.5 Hz, 1H), 3.43 (dd, ^2J = 13.5 Hz, ^3J = 6.8 Hz, 1H), 3.36 (dd, ^2J = 13.5 Hz, ^3J = 6.8 Hz, 1H), 2.38 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$, 60 °C): δ 173.0, 138.5, 137.7, 136.5, 129.5, 129.4, 129.3, 129.1, 128.7, 128.5, 128.4, 127.9, 127.1, 126.9, 126.8, 126.7, 126.6, 62.3, 47.7, 38.5, 21.1. IR: ν_{max} (KBr) 1635 (C═O). HRMS: calcd for $C_{29}H_{27}NONa^+$ 428.1979, found 428.1985.

*N-Benzyl-N-(1-p-tolylpropyl)benzamide (**2g**).* Isolated yield 74%. Clear oil. ^{1}H NMR (500 MHz, $CDCl_3$, 50 °C): δ 7.12−7.40 (m, 13H), 5.20 (br, 1H), 4.72 (br, 1H), 4.28 (d, J = 15.3 Hz, 1H), 2.39 (s, 3H), 2.37 (s, 3H), 1.96 (m, 2H), 0.86 (b, 3H). ^{13}C NMR (125 MHz, $CDCl_3$, 50 °C): δ 173.2, 139.3, 139.2, 137.5, 136.5, 134.9, 129.4, 129.2, 128.3, 128.0, 127.8, 127.1, 126.9, 62.5, 47.0, 25.4, 21.2, 21.1, 11.6. IR: ν_{max} (KBr) 1634 (C═O). HRMS: calcd for $C_{25}H_{27}ONNa^+$ 380.1980, found 380.1985.

*N-Benzyl-N-((4-fluorophenyl)(phenyl)methyl)furan-2-carboxamide (**2h**).* Isolated yield 70%. Yellow solid, mp 65−67 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.84−7.42 (m, 17H), 6.42 (s, 1H), 4.96 (d, J = 16.4 Hz, 1H), 4.80 (d, J = 16.4 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.3 (d, $^1J_{C-F}$ = 245.3 Hz), 161.5, 148.0, 144.4, 139.0, 138.0, 135.0 (d, $^4J_{C-F}$ = 3.2 Hz), 131.2 (d, $^3J_{C-F}$ = 8.1 Hz), 129.0, 128.7, 128.1, 127.9, 127.1, 126.7, 117.3, 115.3 (d, $^2J_{C-F}$ = 21.4 Hz), 111.7, 63.8, 49.9. IR: ν_{max} (KBr) 1628 (C═O). HRMS: calcd for $C_{25}H_{20}O_2NFNa^+$ 408.1369, found 408.1370.

*N-Benzyl-N-(phenyl(p-tolyl)methyl)isobutyramide (**2i**).* Isolated yield 57%. White solid, mp 65−67 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.64−7.26(m, 15H), 4.82 (s, 2H), 2.80 (br, 1H), 2.30 (s, 3H), 1.18 (b, 6H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 178.8, 140.0, 138.8, 137.3, 136.7, 129.2, 128.7, 128.6, 128.4, 128.0, 127.5, 126.5, 115.6, 62.2, 48.7, 31.7, 21.0, 20.0. IR: ν_{max} (KBr) 1635 (C═O). HRMS: calcd for $C_{25}H_{27}ONNa^+$ 380.1990, found 380.1983.

*N-(4-Methoxyphenyl)-4-nitro-N-(phenyl(p-tolyl)methyl)-benzamide (**2j**).* Isolated yield 83%. Yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.48−8.02 (m, 18H), 3.64 (s, 3H) 2.39 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 169.2, 158.9, 143.5, 139.0, 137.6, 135.6, 135.0, 131.5, 129.7, 129.7, 129.5, 129.2, 128.5, 127.8, 127.3, 123.2, 114.0, 65.0, 55.4, 21.3. IR: ν_{max} (KBr) 1646 (C═O). HRMS: calcd for $C_{28}H_{24}O_4N_2Na^+$ 475.1626, found 475.1628.

*(E)-N-Allyl-N-(1,3-diphenylallyl)-4-methylbenzamide (**2k**).* Isolated yield 62%. Clear oil. ^{1}H NMR (500 MHz, $CDCl_3$, 50 °C): δ 7.21−7.45 (m, 14H), 6.58 (br, 2H), 5.81 (br, 2H), 5.04 (d, J = 9.5 Hz, 2H), 4.22 (b, 1H), 3.84 (dd, 1H), 2.39 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$, 50 °C): δ 172.5, 139.8, 139.7, 136.8, 135.1, 134.2, 133.8, 129.3, 128.9, 128.8, 128.2, 127.9, 127.2, 126.9, 126.9, 126.8, 116.7, 63.6, 47.7, 21.5. IR: ν_{max} (KBr) 1635 (C═O). HRMS: calcd for $C_{26}H_{25}ONNa^+$ 390.1825, found 390.1828.

*N-Benzyl-4-methyl-N-(2-methyl-1-phenylpropyl)benzamide (**2l**).* Isolated yield 62%. White solid, mp 55−57 °C. ^{1}H NMR (300 MHz, CD_3CN, 80 °C): δ 6.83−7.40 (m, 14H), 4.65−4.96 (b, 2H), 4.38 (d, J = 15.3, 1H), 2.71 (br, 1H), 3.39 (s, 3H), 1.16 (d, 3H), 0.78 (d, 3H). ^{13}C NMR (68 MHz, CD_3CN, 80 °C): δ 173.2, 139.5, 139.4, 139.2, 135.8, 129.8, 129.6, 128.7, 128.0, 127.8, 127.6, 127.1, 126.8, 69.6, 48.1, 29.6, 20.4, 20.3. IR: ν_{max} (KBr) 1633 (C═O). HRMS: calcd for $C_{25}H_{27}ONNa^+$ 380.1990, found 380.1983.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

^{1}H and ^{13}C NMR spectra for compounds **2a**−**l**, **3**, and **4**. 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.

■ ACKNOWLEDGMENTS

We thank NSERC, FQRNT, and CFI for their financial support of this research.

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(15) The intermediate **3** is formed in equilibrium and cannot be isolated in clean form. However, its in situ ^{1}H and ^{13}C NMR data are consistent with its formation. See Supporting Information for spectral data.
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dx.doi.org/10.1021/jo202339v | *J. Org. Chem.* 2012, 77, 2013−2017