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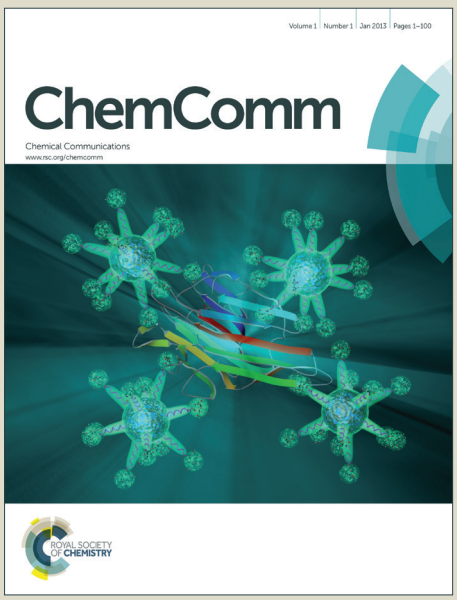

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A novel carbamoyl radical based dearomatizing spiroacylation process.

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An easy entry to novel spirodienonamides based on a dearomatizing spiroacylation process is described for the first time. This process was realized using carbamoylxanthates which were transformed into the spirodienonamides containing an acyl-functionalized all-carbon quaternary center.

The spirodienone system (**II**, Scheme 1) is a molecular motif found in a variety of natural products[1] and represents a fundamental template to build up more complex molecular architectures, both *in vivo* in the biosynthesis of several complex natural products[2] and through synthetic organic chemistry for the construction of molecules of varied complexity. Over the past decades, the direct dearomatizing spirocyclization of phenol derivatives has attracted much attention because this methodology permits straightforward access to the highly valuable spirodienone building block (A, Figure 1). Various methods for the spirocyclization of C-4 phenolic derivatives have been devised. Several C-C, C-O, or C-N bond forming dearomatizing C-4 ring-closures have been accomplished through an oxidative phenolic coupling reaction (nucleophilic spiro-ring-closure) using different oxidizing metals[3] or hypervalent iodine reagents.[4] The spirodearomatizations of appropriately substituted phenols using Pd-catalyzed processes,[5] electrophilic[6] or radical (electrochemically[7] or chemically[8]) cyclizations, as well as a carbene based insertion process, have been reported.[9] While various types of alkyl, aryl, alkenyl and akynyl groups[3-9] have been attached to C-4 in phenolic dearomatizing spirocyclizations, the direct attachment of an "acyl group" has not been realized (II, Figure 1). This difficult phenolic C-C bond-forming spiroacylating process has remained elusive, although it offers a direct entry to an acyl-functionalized all-carbon quaternary center at the spiro ring junction (B, IV). The challenge in this process centers on the choice of an acyl donating-group of the appropriate electronic nature in the C-4 substituted phenol derivative. Under the broadly used classical oxidative conditions,[3-4] the generation of a problematic nucleophilic acyl-species (B, III, Figure 1) might be necessary to secure the cyclization. It would be more logical to use the innate electrophilic nature of most acylating functional groups (i.e., under typical Friedel-Crafts-type acylation conditions). An examination of previous reports on intramolecular aromatic ionic acylation processes revealed however, that only benzofused systems (i.e. dihydroisoquinolinones[10d]) were isolated under various reaction conditions, when 4-methoxy substituted benzenoid starting materials were used.[10] This outcome may be a consequence of a direct *ortho*-addition and/or a fast *ipso*-attack/rearrangement process as the main mechanistic pathway. Another option for the phenolic spiroacylation process is the scarcely explored use of an acyl-radical donor, in an oxidative homolytic cyclization process.[11]

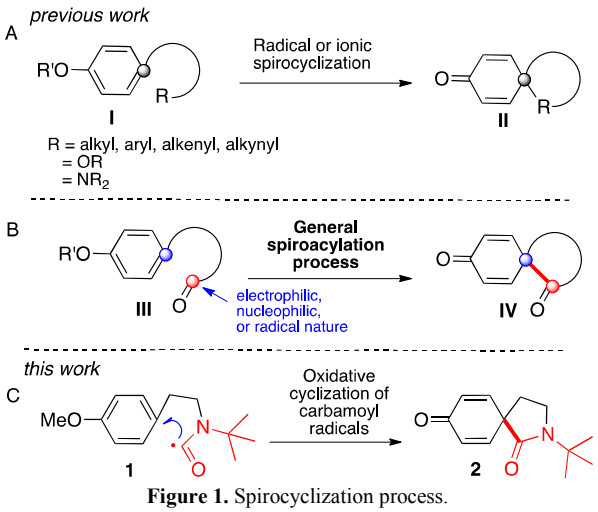
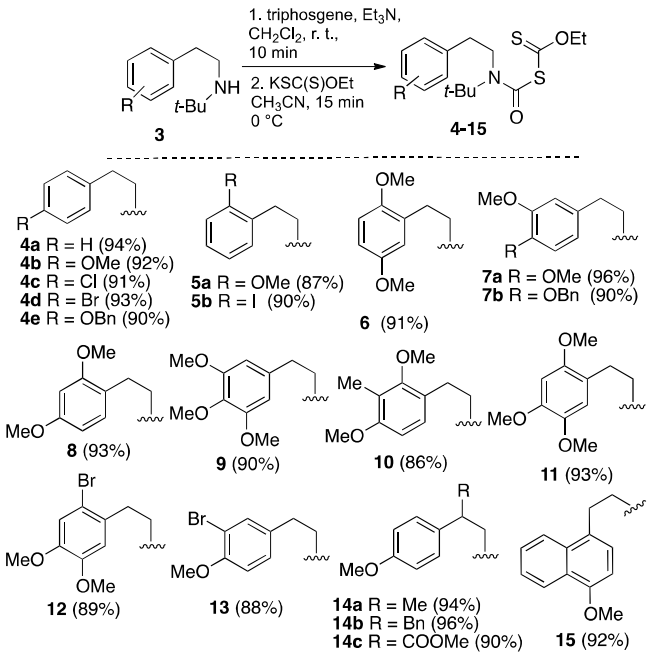


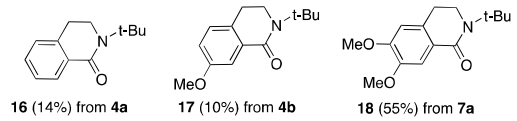
Figure 1. Spirocyclization process.

In this connection, we recently observed that the carbamoyl radical **1** undergoes *ipso*-cyclization to yield the corresponding spirodienone **2** in an oxidative pathway (C, Figure 1). This communication describes our preliminary observations of this latter novel radical spiroacylation. We have previously demonstrated that carbamoyl radicals could be generated from the corresponding carbamoylxanthates.[12] Indeed, the carbamoyl radical derived from

N-*t*-butylbenzylamine cyclized efficiently to the corresponding isoindolone, via a homolytic oxidative aromatic substitution. Significantly, the stability of the carbamoylxanthates depended on the presence of an *N*-*t*-butyl group on the amine moiety. In an attempt to extend this later methodology, we decided to test the carbamoylxanthates (**4**-**15**) derived from the phenethylamine homologues **3** in the radical oxidative cyclization. Several *N*-*t*-butyl-*N*-phenethylamines **3** were converted into the corresponding diversely substituted xanthates **4**-**15** in fairly good yields upon treatment of the corresponding phenethylamine with triphosgene and Et_3N, followed by the addition of the potassium ethyl xanthogenate, under the standard conditions established previously (Scheme 1).[12] With these compounds in hand, we examined their oxidative radical cyclization using dilauroyl peroxide as the initiator in refluxing dichloroethane under the conditions reported previously for the cyclization of the parent benzyl amine derived carbamoylxanthate.[12] Unexpectedly, we observed only decomposition with no apparent major product in most of the experiments with xanthates **4**-**15**. When the experiments were carried out under microwave irradiation to shorten the reactions times,[14] the *N*-*t*-butyl-dihydroisoquinolones **16**-**18** were isolated in low yields from the corresponding xanthates **4a**, **4b**, and **7a** (Scheme 2).



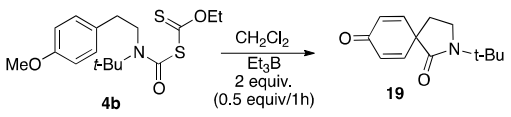
Scheme 1. Synthesis of carbamoylxanthates



Scheme 2. *Conditions:* DLP, dichloroethane, reflux 1h, mw irradiation.

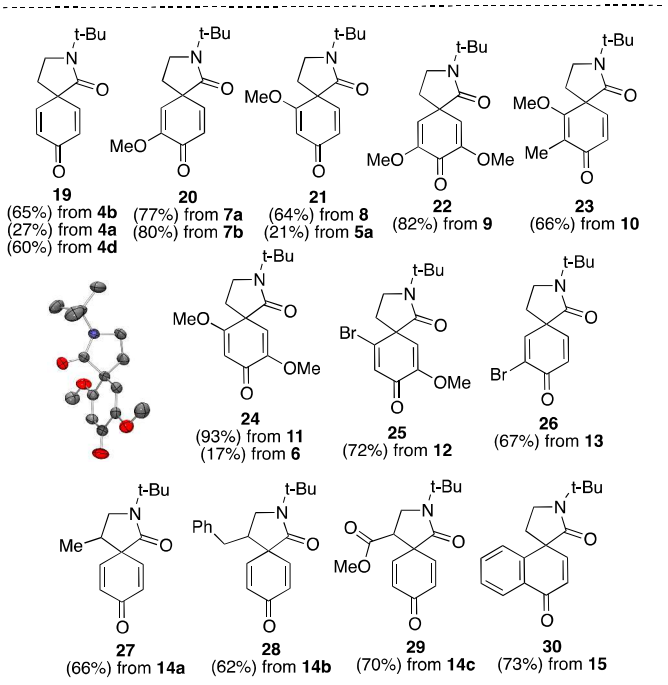
On the assumption that these carbamoylxanthates might be thermally unstable, we evaluated the reaction at room temperature. Previously, we have observed that the Et_3B-mediated radical initiating system facilitated oxidative radical substitutions on pyrrole and indole aromatic systems.[13] We were gratified to observe that, when the *p*-methoxy substituted carbamoylxanthate **4b** was submitted to Et_3B-mediated conditions in dichloroethane, the spirodienone amide **19** was obtained in 32% yield as the major product at room temperature (Table 1, entry 1). A study of reaction conditions to optimize the yield of this novel spirocyclization product was then undertaken. The presence of $FeSO_4$ did not positively affect the product yield (Table 1 entries 3), either in catalytic or stoichiometric amounts nor did longer addition times (Table 1 entries 3-5). $Fe_2(SO_4)_3$, copper(II) 2-ethylhexanoate and CuI_2 were also screened with no obvious benefit in the product yield (see table S-15, supporting information SI). In contrast, when the reaction was carried out at -5 ºC, the yield was considerably increased and the spirodienone **19** was obtained in reasonable 62% yield (entry 6). At lower reaction temperatures, the consumption of the starting material was not complete (entry 8). Addition of 0.5 equivalents of Et_3B at 40 minutes intervals gave **19** in 65% yield, and these reaction conditions were chosen as the optimal ones (entry 7).

Table 1. Optimization of the spiroacylation process.



Entry	Oxidant	Solvent	Time	Temp.	yield
1	-	CH_2Cl_2	14 h[b]	r.t	32%
2	-	CH_2Cl_2	4 h[c]	r.t	35%
3	$FeSO_4$[a]	THF	4 h[c]	r.t	30%
4	$FeSO_4$[a]	CH_2Cl_2/EtOH/H_2O	14 h[b]	r.t	32%
5	$FeSO_4$[a]	CH_2Cl_2/EtOH/H_2O	4 h[c]	r.t	34%
6	-	CH_2Cl_2	4 h[c]	-5 ºC	62%
7	-	CH_2Cl_2	2.6 h[d]	-5 ºC	65%
8	-	CH_2Cl_2	4 h[c]	-40 ºC	NR

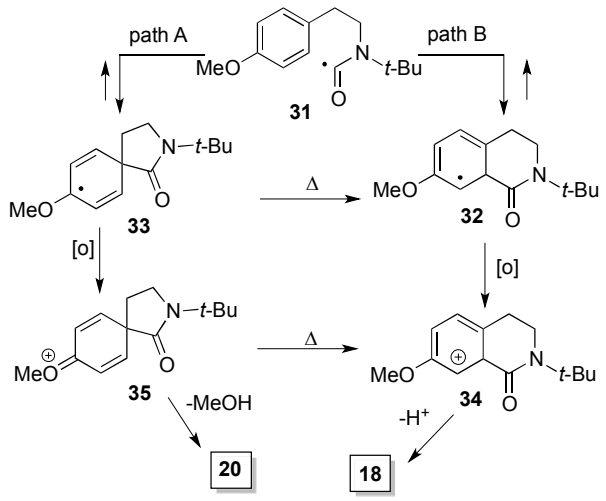
a) 1 equiv. b) 0.14 equiv. of Et_3B/1 h, c) 0.5 equiv. of Et_3B /h, d) 0.5 equiv. of Et_3B /40 min. All reactions were carried out at 0.2M concentration in an open flak system.



Scheme 3. Spiroacylation process. X-Ray ortep structure of **24**.[15]

Accordingly, under the optimized conditions, the monosubstituted spirodienones **20** and **21** were obtained from xanthates **7a** and **8**, respectively, in good yields. Dienones **22**-**24** containing two substituents (OMe or Me) in the dienone moiety were also produced efficiently. The reaction proceeded efficiently even in the presence of an electron attracting bromine substituent at the *ortho* (**25**) or *meta* (**26**) position of the precursor xanthates **12** and **13**. Likewise, phenethylamine xanthate **14a**, substituted in the alkyl chain with a methyl group, afforded the corresponding spirodienone **27** in good yield. A similar outcome was observed with the β-benzyl and β-methoxycarbonyl phenethylamine, derivatives **14b**, and **14c**, which efficiently gave the spiroacylation products **28** and **29**. Furthermore, even the naphthalene derivative **15** afforded the expected benzofused spirodienone **30** very efficiently. Replacement of the *p*-MeO substituent by a benzyloxy group, as in xanthates **4e** and**7b**, did not divert the course of the reaction, the spirodienonamides **19** and **21** nevertheless being obtained in 80% and 60% yields, respectively. Even the diverse substrates **4a**, **5a** and **6** which lacked a *p*-MeO-substituent in the aromatic ring, afforded the corresponding spirodienonamides **19**, **21**, and **24**, respectively, although in low yields. Thus, under these reaction conditions the carbamoyl radical cyclizes at the *ipso*-position without requiring the presence of the otherwise activating methoxyl group.

Previously the formation of related spirodienones in oxidative radical addition of certain alkyl radicals had been observed.[8] Accordingly, the mechanism depicted in Scheme 4 is proposed for the present spiroacylation. Thus, once the carbamoyl radical **31** is generated by a typical xanthate-based radical mechanism,[14] it has two possible cyclization pathways: one that affords the stabilized spiro-radical **33** by an *ipso*-addition (path A, Scheme 4) and another featuring a direct *ortho*-addition to form the new radical **32** (path B). In principle, radicals **32** and **33** might be oxidized to the corresponding cations **34** and **35**, by the action of the peroxyboranes produced in the autoxidation process of the triethylborane.[13,16]



Scheme 4. Proposed mechanism.

In order to have some clues of the preferred cyclization pathway we performed a computational study at M06-2X/6-31++g(d,p)[17] theoretical level of the radical **31** using Gaussian 09 program.[18] We also calculated atomic properties (atomic energies and atomic spin populations) based on Bader's[19] partition with the program AIMAll[20] (see S-2, SI). The group energy associated with the carbamoyl radical allows an estimation of the contribution of the tert-butyl group to the stability of this radical. Interestingly, a stabilizing C-H···O hydrogen bond was observed between the carbamoyl oxygen and one of the methyl groups of the *N*-*t*-butyl moiety, which is characterized by a bond critical point,[21] (Figure S1, SI). The optimized structure of **31** shows a shorter trajectory for the reversible cyclization of the radical to produce the spiro-radical **33** (Figure 2) compared to the direct formation of the six-membered ring in the radical intermediate **32**. Indeed the calculated energy profile revealed that the transition state for the spirocyclization pathway **A** is 4.64 Kcal/mol lower than **B** for the six-membered ring formation (Figure 2). Furthermore, the energy of the cyclized radical **33** is lower than that of **32** by 3.78 Kcal/mol. These differences can be explained by the radical delocalization as described by atomic spin populations (S-2, SI), in which the methoxyl group assists the delocalization of the radical at the *para* carbon atom during the formation of the spiro structure, whereas the six-membered ring formation does not have this assistance. If **A** is the preferred pathway, then the spiroradical **33** might undergo rearrangement to the six-membered **32** congener to produce isoquinolone **18** under thermal conditions although the calculated barrier for this process is 44.05 kcal/mol. Another possibility nonetheless, might be the transformation of the cation **35** into **34** by a thermally induced rearrangement (Scheme 4).

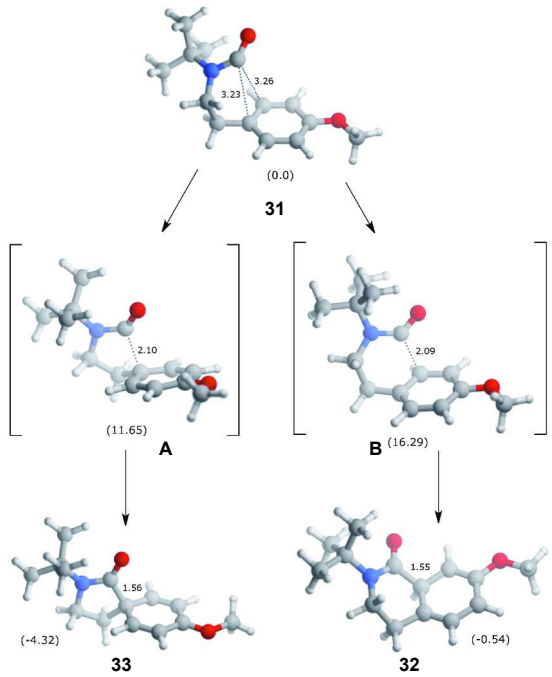


Figure 2. Theoretical calculation of the spiroacylization and six-membered ring formation from carbamoyl radical **31** (bond distances in Å).

Finally, several attempts to remove the of the *N*-*t*-butyl moiety from compound **24** were carried out. The previously described use of neat trifluoromethanesulfonic acid[12] failed. At room temperature, the starting material was recovered, and heating resulted in its destruction. Similar results were obtained with H_2SO_4[8f] and $BF_3{\cdot}2\,CH_3COOH$[22] (S-16, SI).

In closing, an easy entry to novel spirodienonamides featuring, for the first time, a dearomatizing spiroacylation process is described.

This process was realized using carbamoylxanthates which, under Et_3B-mediated radical conditions, were transformed into spirodienonamides containing an acyl-functionalized all-carbon quaternary center. In principle, the process was intended to be applicable only to *p*-MeO-phenethyl derivatives; however, we observed that the spirocyclic dienone was also produced in substrates where no *p*-MeO substituent was present.

Notes and references

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Electronic Supplementary Information (ESI) available: Experimental procedures, NMR spectra and characterization for new materials. See DOI: 10.1039/c000000x/

1. *Selected examples*: (a) S.-G. Ma, R.-M. Gao, Y.-H. Li, J.-D. Jiang, N.-B. Gong, L. Li, Y. Lü, W.-Z. Tang, Y.-B. Liu, J. Qu, H.-N. Lü, Y. Li, and S.-S. Yu, *Org. Lett.*, 2013, **15**, 4450–4453. (b) J.-F. Hu, H. Fan, J. Xiong, and S.-B. Wu, *Chem. Rev.*, 2011, **111**, 5465–5491. (c) J. Sinkkonen, J. Liimatainen, M. Karonen, K. Wiinamäki, P. Eklund, R. Sjöholm, and K. Pihlaja, *Angew. Chem. Int. Ed.*, 2007, **46**, 4148–4150. (d) T. Amagata, K. Minoura, A. Numata, *J. Nat. Prod*. 2006, **69**, 1384–1388. (e) Y. L. Yang, F. R. Chang, and Y. C. Wu, *Helvetica Chimica Acta*, 2004, **87**, 1392–1399. (f) J. S. Liu, L. Li, and H. G. Yu, *Can. J. Chem.*, 1989, **67**, 682–684. (g) P. Daniels, H. Erdtman, K. Nishimura, T. Norin, P. Kierkegaard, and A. M. Pilotti, *J. Chem. Soc., Chem. Commun.*, 1972, 246. (h) B. Gilbert, M. E. A. Gilbert, M. M. De Oliveira, O. Ribeiro, E. Wenkert, B. Wickberg, U. Hollstein, and H. Rapoport, *J. Am. Chem. Soc.*, 1964, **86**, 694–696.

2. (a) S. P. Green and D. A. Whiting, *J. Chem. Soc., Perkin Trans. 1*, 1998, 193–202. (b) D. H. R. Barton, *Pure Appl. Chem.*, 1964, **9**. 35-48. See also: R. A. Bauer, T. A. Wenderski, and D. S. Tan, *Nat. Chem. Biol.* 2012, **9**, 21–29 and references therein.

3. (a) F. C. Pigge, J. J. Coniglio, and N. P. Rath, *J. Org. Chem.*, 2004, **69**, 1161–1168. (b) S. M. Kupchan, V. Kameswaran, J. T. Lynn, D. K. Williams, and A. J. Liepa, *J. Am. Chem. Soc.*, 1975, **97**, 5622–5623.

4. *Recent examples*: (a) H. Nemoto, K. Takubo, K. Shimizu, and S. Akai, *Synlett*, 2012, **23**, 1978–1984. (b) Y. Ye, L. Zhang, and R. Fan, *Org. Lett.*, 2012, **14**, 2114–2117. (c) J. L. Frie, C. S. Jeffrey, and E. J. Sorensen, *Org. Lett.*, 2009, **11**, 5394–5397. (d) J. Y. Cha, G. L. Burnett, Y. Huang, J. B. Davidson, and T. R. R. Pettus, *J. Org. Chem.*, 2011, **76**, 1361–1371. (e) Y. Minamitsuji, D. Kato, H. Fujioka, T. Dohi, and Y. Kita, *Aust. J. Chem.*, 2009, **62**, 648. (f) T. Dohi, Y. Minamitsuji, A. Maruyama, S. Hirose, and Y. Kita, *Org. Lett.*, 2008, **10**, 3559–3562. (g) D. J. Wardrop and M. S. Burge, *J. Org. Chem.*, 2005, **70**, 10271–10284.

5. (a) B. S. Matsuura, A. G. Condie, R. C. Buff, G. J. Karahalis, and C. R. J. Stephenson, *Org. Lett.*, 2011, **13**, 6320–6323. (b) T. Nemoto, Y. Ishige, M. Yoshida, Y. Kohno, M. Kanematsu, and Y. Hamada, *Org. Lett.*, 2010, **12**, 5020–5023.

6. (a) Q. Yin and S.-L. You, *Org. Lett.*, 2012, **14**, 3526–3529. (b) Y. Fan, P. Feng, M. Liu, H. Pan, and Y. Shi, *Org. Lett.*, 2011, **13**, 4494–4497. (c) B.-X. Tang, Q. Yin, R.-Y. Tang, and J.-H. Li, *J. Org. Chem.*, 2008, **73**, 9008–9011. (d) C. Ovens, N. G. Martin, and D. J. Procter, *Org. Lett.*, 2008, **10**, 1441–1444. *See also*: J. S. Swenton, K. Carpenter, Y. Chen, M. L. Kerns, and G. W. Morrow, *J. Org. Chem.*, 1993, **58**, 3308–3316.

7. F. Doi, T. Ohara, T. Ogamino, K. Higashinakasu, K. Hasegawa, and S. Nishiyama, *Bull. Chem. Soc. Jpn.*, 2004, **77**, 2257–2263.

8. (a) F. Diaba, A. Martínez-Laporta, and J. Bonjoch, *J. Org. Chem.*, 2014, **79**, 9365–9372. (b) G. Han, Y. Liu, and Q. Wang, *Org. Lett.*, 2014, **16**, 3188–3191. (c) F. Diaba, J. A. Montiel, A. Martínez-Laporta, and J. Bonjoch, *Tetrahedron Letters*, 2013, **54**, 2619–2622. (d) H. Iwasaki, T. Eguchi, N. Tsutsui, H. Ohno, and T. Tanaka, *J. Org. Chem.*, 2008, **73**, 7145–7152. (e) T. R. Ibarra-Rivera, R. Gamez-Montaño, and L. D. Miranda, *Chem. Commun.*, 2007, 3485. (f) R. Gamez-Montaño, T. Ibarra-Rivera, L. El Kaïm, and L. D. Miranda, *Synthesis*, 2010, **2010**, 1285–1290. (g) F. González-López de Turiso and D. P. Curran, *Org. Lett.*, 2005, **7**, 151–154. (h) J. Boivin, M. Yousfi, and S. Z. Zard, *Tetrahedron Letters*, 1997, **38**, 5985–5988.

9. (a) C. Iwata, K. Murakami, O. Okuda, T. Morie, N. Maezaki, H. Yamashita, T. Kuroda, T. Imanishi, and T. Tanaka, *Chem. Pharm. Bull.*, 1993, **41**, 1900–1905. (b) D. J. Beames and L. N. Mander, *Aust. J. Chem.*, 1974, **27**, 1257–1268.

10. *Selected examples*: (a) J.-Y. Min and G. Kim, *J. Org. Chem.*, 2014, **79**, 1444–1448. (b) K. A. Punch and M. J. Piggott, *Org. Biomol. Chem.*, 2014, **12**, 2801. (c) S. P. Chavan, S. Garai, A. K. Dutta, and S. Pal, *Eur. J. Org. Chem.*, 2012, 6841–6845. (d) H. Kurouchi, K. Kawamoto, H. Sugimoto, S. Nakamura, Y. Otani, and T. Ohwada, *J. Org. Chem.*, 2012, **77**, 9313–9328. (e) B. Andrews, K. Bullock, S. Condon, J. Corona, R. Davis, J. Grimes, A. Hazelwood, and E. Tabet, *Synthetic Commun.* 2009, **39**, 2664–2673. (f) E. Brenna, C. Dei Negri, C. Fuganti, F. G. Gatti, and S. Serra, *Tetrahedron: Asymmetry*, 2004, **15**, 335–340.

11. (a) S. Wertz, D. Leifert, and A. Studer, *Org. Lett.*, 2013, **15**, 928–931. (b) Y. Uenoyama, M. Tsukida, T. Doi, I. Ryu, and A. Studer, *Org. Lett.*, 2005, **7**, 2985–2988. (c) L. D. Miranda, R. Cruz-Almanza, M. Pavón, E. Alva, and J. M. Muchowski, *Tetrahedron Lett.* 1999, **40**, 7153–7157. (d) S. M. Allin, W. R. S. Barton, W. R. Bowman, and T. McInally, *Tetrahedron Lett.* 2001, **42**, 7887–7890.

12. (a) G. López-Valdez, S. Olguín-Uribe, A. Millan-Ortíz, R. Gamez-Montaño, and L. D. Miranda, *Tetrahedron*, 2011, **67**, 2693–2701. (b) G. López-Valdez, S. Olguín-Uribe, and L. D. Miranda, *Tetrahedron Lett.* 2007, **48**, 8285–8289.

13. M. A. Guerrero and L. D. Miranda, *Tetrahedron Lett*. 2006, **47**, 2517–2520.

14. For reviews on xanthate-based radical chemistry see: (a) B. Quiclet-Sire and S. Z. Zard, *Beilstein J. Org. Chem.*, 2013, **9**, 557–576. (b) S. Z. Zard, Xanthates and Related Derivatives as Radical Precursors, in Encyclopedia of Radicals in Chemistry, Biology and Materials John Wiley & Sons, Ltd, Chichester, UK, 2012. (c) B. Quiclet-Sire and S. Z. Zard, *Chem.–Eur. J.,* 2006, **12**, 6002. (d) B. Quiclet-Sire and S. Z. Zard, *Top. Curr. Chem.,* 2006, **264**, 201. (e) S. Z. Zard In Radicals in Organic Synthesis; Renaud, P., Sibi, M., Eds.; Wiley VCH: Weinhem, 2001; p 90.

15 Elipsoids at 30%. Hydrogens were omitted for clarity. CCDC 1017878 contains the crystallographic data for compound **23**. These data can be obtained from: www.ccdc.cam.ac.uk/data_request/cif.

16. C. Ollivier and P. Renaud, *Chem. Rev.*, 2001, **101**, 3415–3434.

17. J. Zheng, and D. G. Truhlar, Phys. *Chem. Chem. Phys*. 2010, **12**, 7782–7793.

18. Gaussian 09, Revision **D.01**, M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, B. Mennucci, G. A. Petersson, H. Nakatsuji, M. Caricato, X. Li, H. P. Hratchian, A. F. Izmaylov, J. Bloino, G. Zheng, J. L. Sonnenberg, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, J. A. Montgomery, Jr., J. E. Peralta, F. Ogliaro, M. Bearpark, J. J. Heyd, E. Brothers, K. N. Kudin, V. N. Staroverov, R. Kobayashi, J. Normand, K. Raghavachari, A. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, N. Rega, J. M. Millam, M. Klene, J. E. Knox, J. B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, R. L. Martin, K. Morokuma, V. G. Zakrzewski, G. A. Voth, P. Salvador, J. J. Dannenberg, S. Dapprich, A. D. Daniels, Ö. Farkas, J. B. Foresman, J. V. Ortiz, J. Cioslowski, and D. J. Fox, Gaussian, Inc., Wallingford CT, 2009.

19. R. F. W. Bader, Atoms in Molecules - A Quantum Theory, Oxford University Press, Oxford, 1990.

20. AIMAll (Version 14.06.21), T. A. Keith, TK Gristmill Software, Overland Park KS, USA, 2014 (aim.tkgristmill.com).

21. E. Arunan, G. R. Desiraju, R. A. Klein, J. Sadlej, S. Scheiner, I. Alkorta, D. C. Clary, R. H. Crabtree, J. J. Dannenberg, P. Hobza, H. G. Kjaergaard, A. C. Legon, B. Mennucci, and D. J. Nesbitt, *Pure Appl. Chem.*, 2011, **83**,1637-1641.

22. M, Dawidowsky, F, Herold, M, Wilczek, J, Turlo, A, Chodkowski, A, Gomolka, and J. Kleps, *Tetrahedron.* 2012, **68**, 8222.

