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The Bromodiazirinyl Anion: A Weakly Bound Complex of Diazirinylidene and a Bromide Ion

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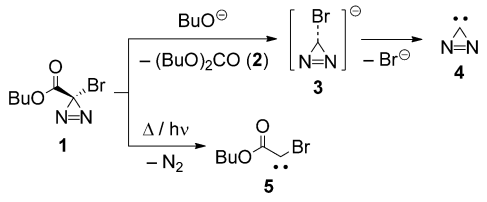
Experimental and computational evidence suggests that the cleavage of *n*-butyl and *tert*-butyl 3-bromodiazirine-3-carboxylates by sodium *n*-butoxide in DMF, affording high yields of dibutyl carbonates, may proceed by nucleophilic acyl displacement of the bromodiazirinyl anion, a weakly bound complex of a cyclic carbene *c*-CN_2 (diazirinylidene) and a bromide ion. We explain the formation of substantial amounts of di-*n*-butoxymethane in the presence of *n*-butanol by a sequence of O–H insertion and denitrogenation reactions of the putative *c*-CN_2 carbene. This ground-state singlet species is the last undescribed member of the CN_2 family of reactive intermediates. It differs from classical N-heterocyclic carbenes by its high ionization potential and electron affinity.

Introduction

3-Halo-3*H*-diazirines and their halogen-exchange derivatives are well known nitrogenous precursors of carbenes.[1] The halogen exchange usually proceeds through 1*H*-diazirines, by two consecutive S_N2'-like reactions on the diazirine ring. In some cases, however, the initial nucleophilic attack occurs in the vicinity of the diazirine ring, resulting in a fragmentation reaction. For example, 3-chloro-3-(*p*-nitrophenoxy)diazirine was recently reported to fragment upon nucleophilic attack on the phenyl ring (S_NAr), competing with the S_N2' exchange on the diazirine ring.[2] Another example is the smooth cleavage of butyl 3-bromodiazirine-3-carboxylate (**1**) to dibutyl carbonate (**2**) and nitrogen gas by the butoxide ion, with no halogen exchange observed.[3] We report experimental and computational evidence that the reaction of **1** may proceed by nucleophilic acyl displacement of the bromodiazirinyl anion (**3**), a weakly bound complex of diazirinylidene (**4**) and a bromide ion (Scheme 1). As **1** affords bromo(butoxycarbonyl)carbene (**5**) under standard thermolytic or photolytic conditions,[3] it can be considered as a chemically and geometrically orthogonal source of two different carbene species and, given the reactivity of **4**, as a single-carbon atom donor.



Scheme 1. Orthogonal cleavage modes of **1**.

Results and Discussion

The known reaction of diazirine ester **1** with sodium butoxide (2 equiv.) in anhydrous *N*,*N*-dimethylformamide (DMF) at –15 °C affords carbonate **2** (76% yield) and nitrogen gas (61% yield).[3] No other major products were detected by NMR spectroscopy when we monitored the reaction in [D_7]DMF. As the ester group of **2** plausibly originates from that of **1**, it is likely the diazirine ring is lost during the reaction in the form of nitrogen gas and dark-colored "polymers". We hypothesized that the reactivity of **1** is dominated by the electrophilicity of its ester group, activated by three electronegative α-heteroatoms. In an attempt to suppress the nucleophilic attack on the ester group in favor of the halogen exchange on the diazirine ring, we have prepared the sterically hindered *tert*-butyl ester **11** from cyanide **6**[4] via trichloroamidine **10**[3] (Scheme 2). However, the exposure of **11** to sodium *n*-butoxide (4 equiv.) in DMF at –15 °C resulted in an instantaneous cleavage to a 66:34 mixture of essentially pure di-*n*-butyl (**2**) and *n*-butyl *tert*-butyl (**12**) carbonates in 79% yield. Control experiments indicated that the product composition is significantly affected by fast transesterification with free butoxide ions, and, therefore, the observed **2**/**12** ratio is unsuitable for mechanistic considerations.

The apparent propensity of diazirine esters **1** and **11** to be attacked by an alkoxide ion at the ester group rather than on the diazirine nitrogen atoms called for a computational study. Our DFT calculations[5] on the model reaction

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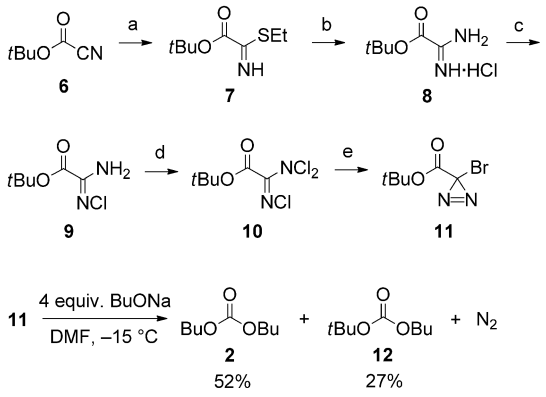
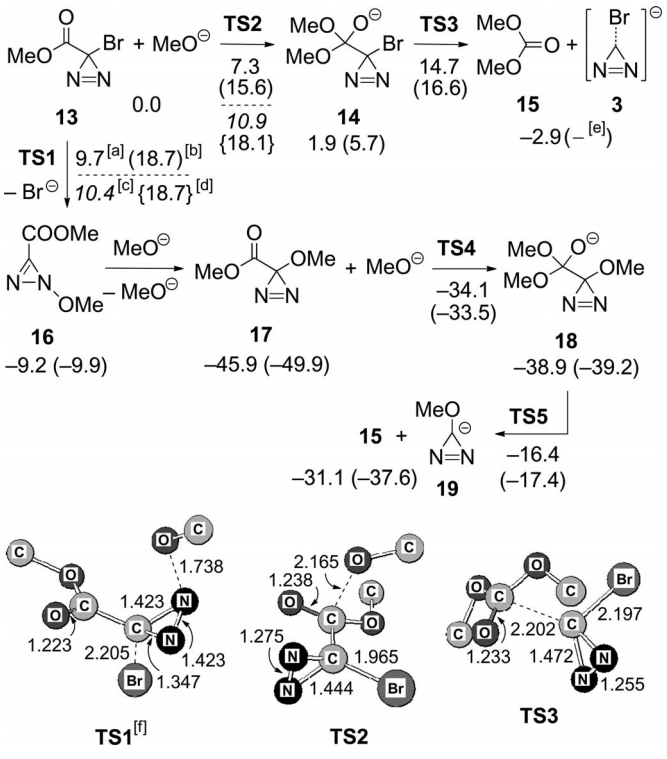


Scheme 2. Preparation and butoxide cleavage of **11**. (a) EtSH, DIEA (*N*,*N*-diisopropylethanamine), 91%; (b) NH_4Cl, MeOH, 57%; (c) aq. NaOCl, Et_2O, 78%; (d) *t*BuOCl, 98%; (e) LiBr, MeCN, 63%.

between methyl ester **13** and the methoxide ion in DMF [CPCM (conductor-like polarizable continuum model) solvation model] showed that the addition of methoxide to the ester carbonyl group of **13**, leading to tetrahedral intermediate **14**, is preferred to the S_N2' bromide displacement, resulting in 1*H*-diazirine **16** (Scheme 3). Free energy differences between the corresponding transition structures **TS2** and **TS1**, calculated at the PBE and B3LYP/6-311+G(d,p) levels, are 2.4 and 3.1 kcal/mol, respectively. As expected, the steric hindrance in *tert*-butyl ester **11** raises the energy of the corresponding **TS2′** with respect to the essentially unaffected **TS1′** [relative free energies calculated at both DFT levels are virtually equal (±0.6 kcal/mol)].

The second step of the halogen exchange pathway, S_N2' isomerization of **16** to 3*H*-diazirine **17**, is strongly exergonic, and we found that it proceeds without a barrier. The fact that our experiments with **1** and **11** yielded only cleavage products, while we have observed no products attributable to the halogen exchange, can be explained by facile irreversible fragmentation of the possibly faster formed intermediate **14** to carbonate **15** (cf. carbonates **2** and **12** obtained experimentally) and **3**. The corresponding **TS3** is calculated to be higher in energy than **TS2** by 7.4 (PBE) or 1.0 kcal/mol (B3LYP). Similar fragmentation of the halogen-exchange product **17** to carbonate **15** and methoxydiazirinyl anion (**19**), proceeding via tetrahedral intermediate **18**, has a much higher activation barrier (ca. 30–33 compared to ca. 15–17 kcal/mol for **13**).

The results of our simplified model calculations thus indicate that the nucleophilic acyl substitution, explaining the observed alkoxide cleavage of diazirines **1** and **11**, should be able to effectively compete with the halogen-exchange reaction commonly observed with halodiazirines, and in DMF the former process is probably somewhat favored. Calculations also show that if a halogen-exchange product was formed, it would be unlikely to fragment to the observed carbonate. Another conceivable mode of decomposition of the **17**-type exchange product is denitro-



Scheme 3. DFT study of methoxide attack on methyl ester **13**. [a] Relative free energies [kcal/mol, 298 K] calculated at the PBE/6-311+G(d,p) level by using the CPCM model for DMF as solvent. [b] Results at the B3LYP level. [c] Corresponding PBE and [d] B3LYP results for *tert*-butyl ester **11** (**TS′**). [e] Anion **3** not found as energy minimum due to its dissociation. [f] Interatomic distances [Å] calculated at the PBE level, hydrogen atoms omitted for clarity.

genation to a stabilized (push–pull) carbene. As will be shown later, products derived from such a carbene should have been detected if they were present.

In principle, the release of a diazirinyl anion (such as in **TS3** or **TS5**) may be feasible. Nonaromatic diazirinyl anions[6] have been directly observed by mass spectrometry[7] and implicated in radical anion processes involving halodiazirines.[8] The unusually long calculated C–Br distance, electron population, and bond orders in anion **3**, however, suggest that it can be interpreted as a complex of the cyclic CN_2 carbene (**4**) with a Br^- ion (Figures 1 and 2). The structure of **3** contrasts with that of **19**, which possesses only a slightly elongated C–O bond, and the majority of negative charge is localized on the ring, as expected for a regular diazirinyl anion. The features of anions **3** and **19** agree with free energies of their dissociation calculated at the PBE/6-311+g(d,p) level (Table 1). Whereas the dissociation of **3** to **4** and a bromide ion in DMF is mildly exergonic, the release of a methoxide ion from **19** is strongly endergonic.

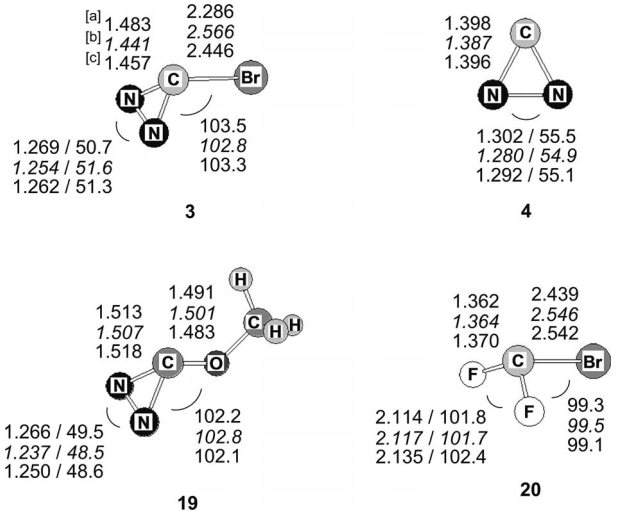


Figure 1. Calculated bond lengths [Å] and angles [°] for **3**, **4**, **19**, and **20**. [a] MP2 level (gas phase). [b] B3LYP level (gas phase). [c] PBE level (DMF). The 6-311+G(d,p) basis set was used in all calculations.

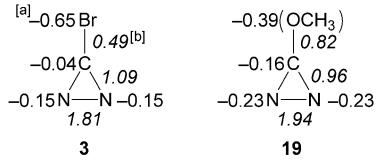


Figure 2. Natural bond orbital analysis of **3** and **19** at the PBE/6-311+G(d,p) level in DMF. [a] Natural charges. [b] Bond orders in terms of Wiberg bond indices.

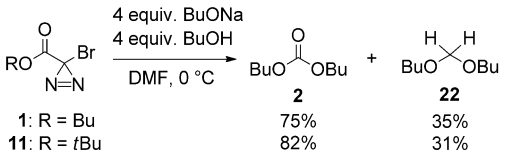
There is a striking resemblance between **3** and difluorohalomethide ions such as $^-CF_2Br$ (**20**) and $^-CF_2Cl$ (**21**), known to be weakly bound complexes of the CF_2 carbene with a bromide and chloride ion, respectively (Figure 1).[9] Free energies of dissociation of **3**, **20**, and **21** are very similar both in the gas phase and in DMF (Table 1). At the B3LYP/6-311+g(d) level, we were unable to locate any of the three anions as an energy minimum in DMF. This result is consistent with the known lability of **20** and **21** towards dissociation; deprotonation of the corresponding haloforms HCF_2Br (**20-H**) and HCF_2Cl (**21-H**) probably leads directly to the CF_2 carbene by a concerted α-elimination.[9a] If the same behavior applies to our bromodiazirine system, carbene **4** could be formed from a **14**-type adduct without the intermediacy of **3**. The similarity of **3** and fluorodihalomethides is further documented by their similar way of generation from α-trihetero-substituted esters. For example, dichlorofluoroacetates are cleaved by alkoxides to dialkyl carbonates (cf. the carbonate formation from esters **1** and **11**) and the $^-CFCl_2$ ion, which subsequently dissociates to the CFCl carbene and a Cl^- ion.[10]

Table 1. Free energies of dissociation of **3** and **19**–**21**.[a]

Process	ΔG_{gas}	ΔG_{DMF}
$^-CN_2Br$ (**3**) → CN_2 (**4**) + Br^-	10.9	–3.2
$^-CN_2OMe$ (**19**) → **4** + MeO^-	42.9	25.0
$^-CF_2Br$ (**20**) → CF_2 + Br^-	9.2	–3.4
$^-CF_2Cl$ (**21**) → CF_2 + Cl^-	12.2	–3.7

[a] Values in kcal/mol at 298 K calculated at the PBE/6-311+G(d,p) level.

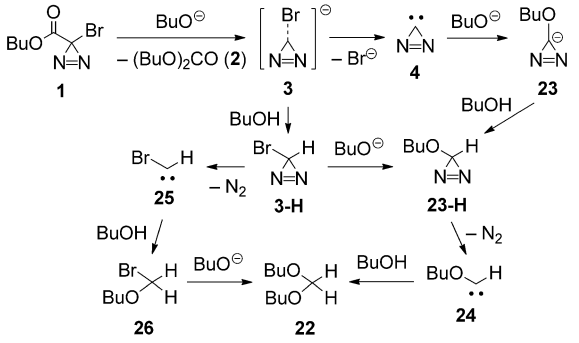
If carbene **4** is indeed an intermediate in the alkoxide cleavage of diazirines **1** and **11**, it should be detectable by a suitable reaction. Thus far, our attempts to trap **4** by cycloaddition to an alkene (2,3-dimethyl-2-butene, cyclohexene) have only resulted in intractable mixtures of products. However, we believe we have found an alternative way of tracing the fate of the diazirine ring carbon atom: The reaction of **1** with butoxide, when performed under strictly aprotic conditions, affords carbonate **2** as the only organic product (vide supra), whereas in the presence of *n*-butanol, we have isolated a virtually unchanged amount of **2** (75%) along with dibutoxymethane (**22**) in 35% yield (Scheme 4). Optimized conditions involve slow addition of **1** to a 0.5 M solution of sodium butoxide (4 equiv.) and *n*-butanol (4 equiv.) in DMF at 0 °C. Under these conditions, diazirine **11** also afforded **2** in 82% yield and **22** in 31% yield. In this case only traces of *tert*-butyl ester **12** (likely converted by transesterification to **2**) and virtually no *n*-butyl/*tert*-butyl scrambling in the acetal was observed.



Scheme 4. Cleavage of **1** and **11** by *n*-butoxide and *n*-butanol.

The diazirine–butoxide/butanol reaction is instantaneous (nitrogen evolution) in DMF even at –40 °C, but also proceeds slowly in pure *n*-butanol. We detected no deuterium incorporation in acetal **22** formed from diazirine **1** in [D_7]-DMF. Based on these observations, the central carbon atoms of **2** and **22** do not originate from the solvent, and mass balance indicates they must come from different parts

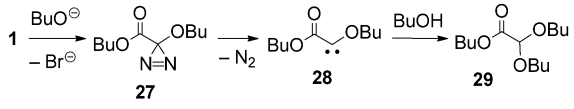
of the starting material (with both **1** and **11**, the sum of yields of **2** and **22** is over 100%). We propose that the central carbon atom of **22** originates from the diazirine ring (Scheme 5). The formation of **22** from **1** can be rationalized by the exchange of bromide in anion **3** to butoxide via strongly electrophilic (vide infra) carbene **4**. The resulting 3-butoxydiazirinyl anion (**23**) is then protonated at the ring carbon atom to form the putative 3-butoxydiazirine (**23-H**), which is expected to undergo nitrogen extrusion. The generated butoxymethylene (**24**) inserts into the O–H bond of *n*-butanol, which completes the formation of **22**. Alternatively, protonation of anion **3** could lead to 3-bromodiazirine (**3-H**), further converted into acetal **22** through halogen exchange to diazirine **23-H**, or through denitrogenation to bromomethylene (**25**), insertion of butanol to bromomethyl ether **26**, and bromide displacement.



Scheme 5. Possible mechanisms of cleavage of **1** by butoxide and butanol.

Unlike the bromide–carbene complex **3**, we expect the butoxy anion **23** to be a regular diazirinyl carbanion[6–8] (as shown above for the simplified methoxy species **19**). Our calculations indicate that the proton affinities of anions **3**, **20**, and **21** are similar and much lower than that of **23** or **19** (Table 2). As the calculated dissociation and protonation energetics of **3**, **20**, and **21** are very similar, and the latter two species are known to dissociate faster than they are protonated,[9a] it is expected that **3** will exhibit the same behavior. We therefore believe that the dissociation of anion **3** to carbene **4** followed by the addition of butoxide, which results in anion **23** (from data in Table 1, ΔG = –28 kcal/mol for **3** → **19** in DMF), is more likely than the initial protonation of **3** (Scheme 5), and the intermediacy of carbene **4** is thus plausible. The possibility of direct formation of **4** by a concerted α-elimination from the tetrahedral intermediate upon the addition of alkoxide to the diazirine ester group should also be considered (Scheme 3).

The slow reaction of diazirine **1** with butoxide in pure *n*-butanol did not reach full conversion after 24 h at 0 °C, and a mixture of **1**, **2**, **22**, and dibutoxyacetate **29** in a ca. 2:2:1:1.5 ratio was isolated. In this case, nucleophilic acyl substitution (producing **2** and **22**) and halogen exchange appear to proceed concurrently, as the formation of **29** can be explained by the insertion of stabilized (push–pull) carbene **28**, resulting from denitrogenation of the substitution product **27**, into the solvent O–H bond (Scheme 6). As diazirine **1** is thermally stable at 0 °C, it is unlikely that acetate **29** is formed via carbene **5** (Scheme 1). Importantly, we have verified that an authentic sample of **29**[11] does not cleave to **2** and **22** upon treatment with butoxide/butanol in DMF or in pure alcohol. This observation corroborates the idea that carbonates **2** or **12** and acetal **22** do not result from halogen exchange of diazirines **1** or **11**, and had halogen exchange proceeded in DMF to an appreciable extent, its products should be observable (in fact, we have detected traces of **29** by GC–MS in the crude products of reactions of **1** or **11** in DMF).



Scheme 6. Proposed mechanism of formation of **29** from diazirine **1**.

From an experimental point of view, **4** has been an undescribed reactive intermediate, whereas its silicon analog, 1-sila-2,3-diazacyclopropenylidene (**30**), was matrix-isolated a decade ago (Figure 3).[12] Cyclopropenylidene (**31**), a carba analogue of **4**, is abundant in the interstellar medium and was matrix-isolated in the 1980s.[13] Carbene **4** has appeared in several theoretical studies,[14,15] but has been mostly considered in the broader context of the other CN_2 species, cyanonitrene (**32**) and diazomethylene (**33**), which were both matrix-isolated in the 1960s.[16] Although **4** is calculated to be a ground-state singlet ($\Delta E_{S-T} \approx$ –30 to –35 kcal/mol), **32** and **33** have been found to be ground-state triplets experimentally (ΔE_{S-T} = 23.3 and 19.5 kcal/mol, respectively).[17] The order of calculated relative gas-phase energies (in kcal/mol) is ^{3}**32** (0), ^{1}**4** (25.3), and ^{3}**33** (28.9).[14e]

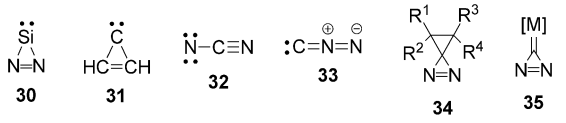


Figure 3. Species related to carbene **4**.

Table 2. Relative proton affinities of anions **3** and **19**–**21**.[a]

Process	ΔG
HCN_2OMe (**19-H**) + $^-CN_2Br$ (**3**) → $^-CN_2OMe$ (**19**) + HCN_2Br (**3-H**)	15.7
HCF_2Br (**20-H**) + **3** → $^-CF_2Br$ (**20**) + **3-H**	–1.7
HCF_2Cl (**21-H**) + **3** → $^-CF_2Cl$ (**21**) + **3-H**	1.7

[a] Values in kcal/mol at 298 K calculated at the PBE/6-311+G(d,p) level in DMF.

Carbene **4** differs from classical N-heterocyclic carbenes (NHCs) by its very high ionization potential (*IP*) – calcd. *IP* = 12.3 eV, typical NHC calcd. *IP* ≈ 8 eV – and high electron affinity (*EA*) – calcd. *EA* = 0.89 eV, typical NHC calcd. *EA* ≈ –0.5 eV (Figure 4).[18] The high *IP* and *EA* of **4** are more features it shares with fluorocarbenes (for CF_2, calcd. *IP* = 12.3 eV, *EA* = 0.0 eV; for CFCl, calcd. *IP* = 11.0 eV, *EA* = 0.84 eV).

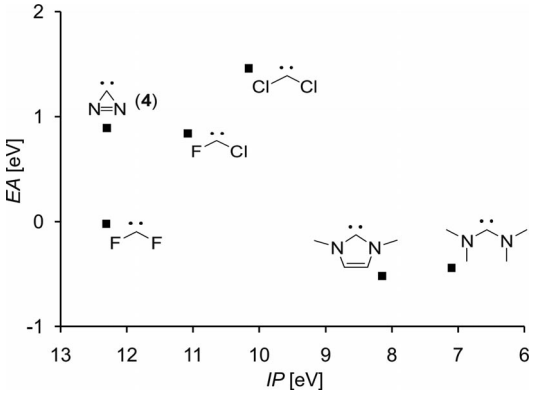


Figure 4. *IP* and *EA* values of carbenes calculated at the (U)B3LYP/6-311+G(d) level.[18]

By nature, carbene **4** is expected to be an elusive species. We are currently searching for its direct trapping products, which are spirocyclic alkene adducts (**34**) and transition metal complexes (**35**). The major issue in finding such unprecedented species is the inherent lability of their diazirine ring, complicating their isolation and characterization. The viability of searching for **35** is supported by a recent computational study indicating that the binding energy of **4** to some transition metals (AuCl test particle) is comparable to that of phosphanes (but smaller than that of NHCs).[15]

Conclusions

We have found experimental and computational evidence for the competition between bromide exchange and nucleophilic acyl displacement of the bromodiazirinyl anion (**3**) in the reactions of *n*- or *tert*-butyl 3-bromodiazirine-3-carboxylates (**1** or **11**) with sodium *n*-butoxide. Although in *n*-butanol both reactions proceed concurrently, the latter predominates in DMF. We interpret anion **3** as a weakly bound complex of the cyclic carbene *c*-CN_2 (**4**) with a bromide ion. The intermediacy of **4** is supported by the isolation of substantial amounts of dibutoxymethane (**22**) when the *n*-butoxide substitution reactions are carried out in the presence of *n*-butanol. We propose a mechanism in which **22** is formed from carbene **4** by a sequence of O–H insertions and denitrogenation. The ground-state singlet **4** (diazirinylidene) is the last experimentally undescribed member of the CN_2 family of reactive intermediates, which differs from classical NHCs by its high ionization potential and electron affinity.

Experimental Section

Caution! Neat diazirines are potentially shock-sensitive and may violently decompose without warning. All operations with neat diazirines should be carried out behind a safety shield. However, we have not experienced any violent decomposition of diazirines **1** *and* **11**.

General Methods: Lithium bromide was dried at 250 °C under a 2×10^{-2} Torr vacuum for 48 h and was used immediately. *n*-Butanol, DMF, and acetonitrile were distilled from calcium hydride. All other chemicals were used as purchased.

***tert*-Butyl 2-Ethylthio-2-iminoacetate (7):** A mixture of *tert*-butyl cyanoformate (**6**)[4] (9.0 g, 70.8 mmol) and ethanethiol (10.5 mL, 142 mmol) in a 100 mL round-bottomed flask was cooled to 0 °C. After addition of DIEA (12.2 mL, 71.2 mmol), the reaction mixture was stirred at 0 °C for 30 min and then at room temperature for 17 h. Unreacted thiol was evaporated at 0 °C (water aspirator vacuum) through a trap at –78 °C containing diethyl ether (50 mL), and the residual amine was removed at room temperature (3×10^{-1} Torr). This procedure afforded 12.2 g (91%) of **7** as a yellow liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 10.38 (br. s, 1 H, NH), 2.96 (q, *J* = 7.0 Hz, 2 H, CH_2S), 1.52 (s, 9 H, *t*BuCH_3), 1.30 (t, *J* = 7.5 Hz, 3 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 168.9 (C=O), 157.6 (C=N), 84.4 (*t*BuCO), 27.6 (*t*BuCH_3), 24.1 (CH_2S), 13.2 (CH_3) ppm. HRMS (TOF ES$^+$): calcd. for $C_8H_{15}NO_2SNa$ [M + Na]$^+$ 212.0721; found 212.0738.

(*tert*-Butoxycarbonyl)formamidine Hydrochloride (8): A mixture of **7** (11.0 g, 58.1 mmol), finely powdered ammonium chloride (3.11 g, 58.1 mmol), and methanol (30 mL) was heated to reflux in a 100 mL round-bottomed flask for 1 h, and the escaping ethanethiol was condensed in a –78 °C trap containing diethyl ether (50 mL). The reaction mixture was cooled to room temperature, and methanol was removed under reduced pressure. The residue was thoroughly triturated with diethyl ether and the resulting solid dried in vacuo. This procedure afforded 7.20 g of crude **8** with 83.3% (w/w) purity by ^{1}H NMR spectroscopy, the remaining 16.7% being the unreacted ammonium chloride (the total yield of **8** was 57%). The crude product was used directly in the next step (preparation of *N*-chloroamidine **9**). A purified sample of **8** (m.p. >250 °C) was obtained by several cycles of fractional dissolution in *tert*-butyl alcohol followed by concentration of the mother liquor. ^{1}H NMR (300 MHz, [D$_6$]DMSO): δ = 9.77 (br. s, 2 H, NH_2), 9.66 (br. s, 2 H, NH_2), 1.50 (s, 9 H, *t*BuCH_3) ppm. ^{13}C NMR (75 MHz, [D$_6$]-DMSO): δ = 155.53 (C=O), 155.45 (C=N), 86.8 (*t*BuCO), 27.3 (*t*BuCH_3) ppm. HRMS (TOF ES$^+$): calcd. for $C_6H_{13}N_2O_2$ [M – Cl]$^+$ 145.0977; found 145.0985.

(*tert*-Butoxycarbonyl)-*N*-chloroformamidine (9): To a vigorously stirred suspension of crude **8** [7.00 g, corresponding to 5.83 g (32.3 mmol) of pure **8** and 1.17 g (21.9 mmol) of ammonium chloride] in water (20 mL) and diethyl ether (250 mL) in a 500 mL round-bottomed flask cooled below 5 °C was added a 5.04% (iodometric) solution of commercial bleach (74.4 g, 50.4 mmol of sodium hypochlorite) dropwise maintaining a temperature below 10 °C. When the addition was completed, the mixture was stirred for another 5 min. The two layers were separated, and the aqueous phase was extracted with diethyl ether (2 × 300 mL). The combined organic phases were dried with $MgSO_4$ and concentrated under reduced pressure below room temperature to afford 4.52 g (78% yield) of **9** as a white solid. M.p. 70.4–71.0 °C (pentane/diethyl ether). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.01 (br. s, 1 H, NH), 5.75 (br. s, 1 H, NH), 1.56 (s, 9 H, *t*BuCH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 158.0 (C=O), 155.7 (C=N), 85.3 (*t*BuCO), 27.8 (*t*BuCH_3) ppm. HRMS (TOF ES$^+$): calcd. for $C_6H_{11}ClN_2O_2Na$ [M + Na]$^+$ 201.0407; found 201.0410.

(*tert*-Butoxycarbonyl)-*N*,*N*,*N*′-trichloroformamidine (10): A solution of **9** (4.00 g, 22.4 mmol) in *t*BuOCl (36 g, 332 mmol) was stirred at room temperature in the dark for 24 h. Upon concentration under reduced pressure at room temperature, 5.42 g (98% yield) of **10** was obtained as a yellow liquid with a strong chlorine-like odor, which solidified below room temperature. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.59 (s, 9 H, *t*BuCH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 166.5 (C=O), 155.8 (C=N), 87.7 (*t*BuCO), 27.8 (*t*BuCH_3) ppm. HRMS (EI$^+$): calcd. for $C_6H_9Cl_3N_2O_2$ $[M]^+$ 245.9730; found 245.9719.

***tert*-Butyl 3-Bromodiazirine-3-carboxylate (11):** To a vigorously stirred solution of dry lithium bromide (26.0 g, 299 mmol) in dry acetonitrile (450 mL) in a 1 L round-bottomed flask in the dark was added **10** (5.00 g, 20.2 mmol) in acetonitrile (40 mL) dropwise over 15 min. When the addition was completed, the mixture was stirred for another 10 min and then extracted into pentane (6 × 500 mL). The combined pentane layers were concentrated under reduced pressure below 10 °C affording 2.81 g (63%) of a pale-yellow liquid, essentially pure **11** by ^{1}H NMR spectroscopy. For UV/Vis spectroscopic purposes the product was further purified by fractional vacuum transfer (4×10^{-2} Torr) at room temperature into a U-trap cooled to –196 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.46 (s, 9 H, *t*BuCH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 162.2 (C=O), 85.9 (*t*BuCO), 31.3 (CN_2), 27.6 (*t*BuCH_3) ppm. IR (film, NaCl): $\tilde{\nu}$ = 1754, 1735, 1605 cm^{-1}. UV (pentane): λ_{max} (ε, L mol^{-1} cm^{-1}) = 308 (ca. 16), 323 (ca. 29), 335 (ca. 32) nm.

Reaction of 11 with Sodium Butoxide in DMF: Sodium metal (115 mg, 5.00 mmol) was dissolved in dry *n*-butanol (10 mL) in a 50 mL round-bottomed flask (magnetically stirred, under argon). Excess butanol was evaporated below room temperature, and the resulting solid sodium butoxide was dried at 45 °C for 12 h (both operations were performed under a 2×10^{-2} Torr vacuum). The sodium butoxide was quickly dissolved in dry DMF (9.0 mL), and the solution was cooled to –15 °C. Diazirine **11** (276 mg, 1.25 mmol) in DMF (0.5 mL) was added dropwise with vigorous stirring over 20 min. Nitrogen evolution and frothing occurred upon each addition of starting material solution. Immediately after the addition was complete, the reaction mixture was diluted with water (50 mL) and extracted with pentane (4 × 50 mL). The combined extracts were washed with water (2 × 100 mL), dried with magnesium sulfate, and concentrated under reduced pressure at 0 °C. The resulting yellow-brown oil (182 mg) was identified by comparison to authentic samples to be a 95% pure mixture of di-*n*-butyl carbonate (**2**)[19a] (114 mg, 52% yield) and *n*-butyl *tert*-butyl carbonate (**12**)[19b] (58 mg, 27% yield). The yields were determined by ^{1}H NMR spectroscopy with naphthalene as an internal standard. **2**: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.10 (t, J = 6.7 Hz, 4 H, CH_2O), 1.63 (quint, J = 6.7 Hz, 4 H, CH_2), 1.38 (sext, J = 7.3 Hz, 4 H, CH_2), 0.91 (t, J = 7.3 Hz, 3 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 155.4 (C=O), 67.6 (CH_2O), 30.7 (CH_2), 18.9 (CH_2), 13.6 (CH_3) ppm. **12**: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.03 (t, J = 6.7 Hz, 2 H, CH_2O), 1.67–1.57 (m, 2 H, CH_2), 1.46 (s, 3 H, *t*BuCH_3), 1.45–1.32 (m, 2 H, CH_2), 0.92 (t, J = 7.3 Hz, 3 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 153.7 (C=O), 81.7 (*t*BuCO), 66.9 (CH_2O), 30.7 (CH_2), 27.7 (*t*BuCH_3), 18.9 (CH_2), 13.6 (CH_3) ppm.

Reaction of 1 or 11 with Sodium Butoxide and *n*-Butanol in DMF: Sodium butoxide (5.00 mmol), prepared as described above, was quickly dissolved in dry DMF (9.0 mL) and *n*-butanol (0.458 mL, 5.00 mmol), and the solution was cooled to 0 °C. Diazirine **1**[3] or **11** (276 mg, 1.25 mmol) in DMF (0.5 mL) was added dropwise with vigorous stirring over 20 min (prolonged exposure of DMF to butoxide/butanol results in the formation of dimethylamine, causing lower reaction yields). Nitrogen evolution and frothing occurred upon each addition of starting material solution. After the addition was complete, the reaction mixture was stirred at room temperature for 20 min, and was worked up as described above. The resulting yellow-brown oil was identified by comparison to authentic samples to be a mixture of **2** and dibutoxymethane (**22**),[19c] 90–94% pure by ^{1}H NMR spectroscopy. Yields were determined by ^{1}H NMR spectroscopy with naphthalene as an internal standard. Crude product from reaction with **1**: 248 mg, of which 163 mg (75% yield) was **2** and 70 mg (35% yield) was **22**; crude product from reaction with **11**: 268 mg, of which 179 mg (82% yield) was **2** and 62 mg was **22** (31% yield). **22**: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.65 (s, 2 H, OCH_2O), 3.52 (t, J = 6.6 Hz, 4 H, CH_2O), 1.60–1.51 (m, 4 H, CH_2), 1.43–1.31 (m, 4 H, CH_2), 0.92 (t, J = 7.3 Hz, 3 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 95.2 (OCH_2O), 67.5 (CH_2O), 31.8 (CH_2), 19.4 (CH_2), 13.8 (CH_3) ppm.

Reaction of 1 with Sodium Butoxide in *n*-Butanol: Sodium metal (57 mg, 2.50 mmol) was dissolved in *n*-butanol (4.0 mL) in a 10 mL round-bottomed flask (magnetically stirred, under argon). After the solution had been cooled to 0 °C, **1**[3] (276 mg, 1.25 mmol) in butanol (0.5 mL) was added dropwise with vigorous stirring over 5 min. After stirring at 0 °C for 24 h, the reaction mixture was diluted with water (70 mL), and extracted with pentane (5 × 100 mL). The combined extracts were washed with water (3 × 250 mL), dried with magnesium sulfate, and concentrated under reduced pressure at 0 °C. The resulting yellow oil (96 mg) was identified by comparison to authentic samples to be a mixture of unreacted **1**, **2**, **22**, and butyl dibutoxyacetate (**29**)[11] in a ca. 2:2:1:1.5 ratio. **1**: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.22 (t, J = 6.6 Hz, 2 H, CH_2O), 1.65 (m, 2 H, CH_2), 1.38 (m, 2 H, CH_2), 0.94 (t, J = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 163.6 (C=O), 68.2 (CH_2O), 30.3 (CH_2), 30.0 (CN_2), 18.8 (CH_2), 13.5 (CH_3) ppm. **29**: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.87 (s, 1 H, OCHO), 4.18 (t, J = 6.7 Hz, 2 H, CH_2O_2C), 3.65–3.51 (m, 4 H, CH_2O), 1.70–1.55 (m, 6 H, CH_2, CH_2), 1.45–1.32 (m, 6 H, CH_2, CH_2), 0.93 (t, J = 7.3 Hz, 3 H, CH_3), 0.91 (t, J = 7.3 Hz, 6 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 167.7 (C=O), 97.8 (OCHO), 66.6 (CH_2O), 65.1 (CH_2O_2C), 31.6 (CH_2), 30.5 (CH_2), 19.2 (CH_2), 19.0 (CH_2), 13.8 (CH_3), 13.6 (CH_3) ppm.

Supporting Information (see footnote on the first page of this article): NMR spectra for **1**, **2**, **7**–**12**, **22**, and **29**; IR and UV spectra for **11**; details of DFT calculations.

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