A New Synthesis of 2-Methyleneaziridines

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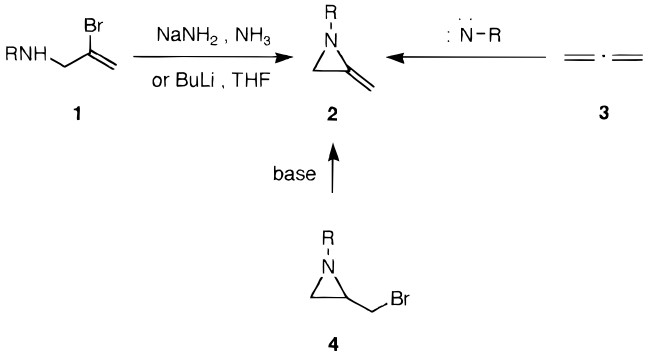
A new synthetic route leading to 2-methyleneaziridines has been developed by base-induced 1,2-dehydrobromination of 2-(bromomethyl)aziridines. Several base-solvent pairs did not lead to 2-methyleneaziridines. Only potassium *tert*-butoxide in tetrahydrofuran afforded 2-methyleneaziridines in competition with the substitution products, *i.e.* 2-(*tert*-butoxymethyl)aziridines. Various attempted functionalizations of 1-(arylmethyl)-2-methyleneaziridines failed, but they proved to be excellent substrates for the synthesis of β-lactam derivatives, *i.e.* 1-(arylmethyl)-2-iminoazetidines, through ring expansion with azides carrying electron-withdrawing substituents.

Introduction

2-Methyleneaziridines **2** belong to a rare class of highly strained heteromethylenecyclopropanes, which caught a lot of interest in view of their potential to give valence isomerizations. There are only a few synthetic routes leading to 2-methyleneaziridines, the most general one being the cyclization of 2-bromo-2-propenylamines **1** with sodium amide in liquid ammonia[1−4] or butyllithium in tetrahydrofuran[5] (Scheme 1). The cycloaddition of allenes, *e.g.* **3**, with nitrenes[6] carrying electron-withdrawing substituents offers access to a few 2-methyleneaziridines in very low yield (3−8%),[6] while the synthesis of a highly functionalized 2-(bromomethylene)aziridine via electrobromination of 1-acetoxy-4-(*N*-acetylamino)-4-methyl-1-phenyl-2-pentyne has to be considered as an exceptional case.[7] Some 2-methyleneaziridines have been postulated as intermediates, for instance during the rearrangement of 2-chloro-2-methylaziridines with potassium *tert*-butoxide[8] or during the cycloaddition of phthalimidonitrene across functionalized allenes.[9] 2-Methyleneaziridines can be functionalized by deprotonation with *n*-butyllithium[10] or *sec*-butyllithium[11] and subsequent reaction with electrophiles. 2-Methyleneaziridines have been shown to be suitable sources for the synthesis of heterocycles, *e.g.* 1-azaspiro[2,3]hexanes,[12] pyrroles,[12] 4-methylene-2-oxazolines,[6] 1,4-diazaspiro[2,2]pentanes,[9] 2-iminoazetidines[13,14] and 3-methylene-2-azetidinones.[15] The protonation at nitrogen of 2-methyleneaziridines in superacid medium with and without ring rupture has been studied.[16,17] A major feature of 2-methyleneaziridines is their propensity to give a valence isomerization to afford an isomeric (if not degenerated) methyleneaziridine and a cyclopropylideneamine, the latter usually fragmenting into an olefin and an isonitrile.[11,18,19]

Scheme 1



An obvious and straightforward entry to 2-methyleneaziridines **2** would be the 1,2-dehydrobromination of 2-(bromomethyl)aziridines **4**, which became recently accessible *via* reductive ring closure of *N*-arylidene-2,3-dibromopropylamines.[20,21] In the present report, the 1,2-dehydrobromination of 2-(bromomethyl)aziridines **4** was investigated, and the resulting 2-methyleneaziridines were converted into 2-iminoazetidines by skeletal rearrangement with organic azides.

Results and Discussion

2-(Bromomethyl)aziridines **7** are accessible from aldehydes **5** in three high yielding steps. Condensation of

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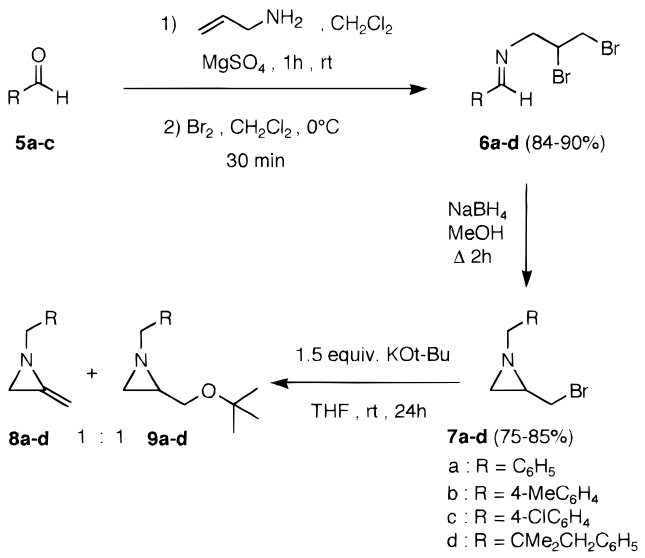
Scheme 2



aldehydes **5** with allylamine in dichloromethane in the presence of magnesium sulfate as drying agent affords the corresponding *N*-allylimines which react smoothly with bromine in dichloromethane to give rise to *N*-(arylidene)-2,3-dibromopropylamines **6**. The latter dibromoimines react with sodium borohydride in methanol under reflux to produce 2-(bromomethyl)aziridines **7** in 35−85% yield (Scheme 2). 2-(Bromomethyl)aziridines **7** are a class of rare and relatively unreactive β-bromo amines. Only one 2-(bromomethyl)aziridine, *i.e.* the *N*-*tert*-butyl derivative, was reported and was obtained from the reaction of 1-*tert*-butyl-2-[(*p*-tosyloxy)methyl]-aziridine with tetrabutylammonium bromide.[22] Only a very few related 2-(chloromethyl)aziridines are accessible either by ring opening of epichlorohydrin with *tert*-butylamine or cyclohexylamine and subsequent ring closure,[23] or by rearrangement of 1-*tert*-butyl-2-(diphenylhydroxymethyl)aziridine with thionyl chloride in the presence of sodium hydride.[24]

In order to find suitable conditions for the transformation of **4** into **2**, the model compound 1-benzyl-2-(bromomethyl)aziridine (**7a**) (R = C_6H_5) was treated with several bases under a variety of conditions. Lithium diisopropylamide or sodium hydride in THF at room temperature for 22 h did not convert 2-(bromomethyl)-aziridine **7a** into 2-methyleneaziridine **8a**. Sodium hydride in benzene did not dehydrobrominate compound **7a**. The temperature had a major outcome on the reaction of **7a** with sodium hydride in dimethyl sulfoxide (DMSO). The dimsyl anion in DMSO did not dehydrobrominate compound **7a** at room temperature (29 h), while a complete consumption but no 2-methyleneaziridine formation was observed at 100−135 °C. No products could be identified from the complex reaction mixture. Various experiments of compound **7a** with the dimsyl anion in DMSO at 45−50 °C during one to three days afforded reaction mixtures containing 20−40% of 2-methyleneaziridine **8a**, contaminated with several unidentified products. These intractable mixtures were not investigated further. DBU in DMSO at room temperature (65 h) or DBU in benzene under reflux (7 h) gave either no reaction or a complex reaction mixture without any sign of 2-methyleneaziridine **8a**, respectively. Also dichloroethylaluminum in toluene at room temperature for 45 min gave no access to 2-methyleneaziridines. In view of the known behavior of 2-(chloromethyl)aziridines to give nucleophilic substitution with alkoxides in the corresponding alcohol, it was no surprise to observe this substitution reaction with compound **7a** and sodium methoxide in methanol or sodium ethoxide in ethanol. The reaction mixtures did not contain a trace of the methyleneaziridine. The reaction of potassium 2,6-di-*tert*-butyl-4-methylphenoxide in THF at room temperature (15 h) or potassium *tert*-butoxide in *tert*-butanol at room temperature (7 h) did not afford a trace of 2-methyleneaziridine **8a**. On the other hand, the reaction of compound **7a** with potassium *tert*-butoxide in *tert*-butyl alcohol under reflux (3 h) produced a reaction mixture in quantitative yield consisting of 20% 2-methyleneaziridine **8a** and 80% 2-(*tert*-butoxymethyl)aziridine **9a**. The best base−solvent pair proved to be potassium *tert*-butoxide (1.5 equiv) in THF, affording a nearly quantitative yield of reaction products **8a** and **9a** in a ratio of 1:1 at room temperature (24 h). Lowering the temperature to 0 °C or −20 °C resulted in a very slow reaction (3 days) leading to roughly the same 1:1 ratio of **8a** and **9a**, but with the unappealing presence of 10% (0 °C → room temperature) or 70% (−20 °C, 3 days) of starting material. The reaction of aziridine **7a** with the more sterically hindered potassium *t*-pentoxide (1.5 equiv) in THF for 12 h under reflux gave also substantial amounts of the substitution product, *i.e.* 1-benzyl-2-(*t*-pentoxymethyl)-aziridine **9c** (21%) alongside with a low isolated yield of 11% of 2-methyleneaziridine **8a**. When potassium 2,3,4-trimethyl-3-pentoxide was used as a base in THF the only reactivity observed was decomposition of the starting material due to prolonged reaction times. The above selected reaction conditions (KO*t*-Bu, THF, 24 h, rt) were applied to three other substrates **7**, namely **7b** (R = 4-MeC_6H_4), **7c** (R = 4-ClC_6H_4) and **7d** (R = CMe_2-$CH_2C_6H_5$), each giving the same 1:1 ratio of 2-methyleneaziridine **8b**−**d** and 2-(*tert*-butoxymethyl)aziridine **9b**−**d**. The 2-methyleneaziridines **8a**−**d** were isolated by high vacuum distillation affording yields of 40−48%. The 2-(*tert*-butoxymethyl)aziridines **9a**−**d** were isolated by high vacuum distillation or flash chromatography (silica gel; hexane:ethyl acetate). Attempts to isolate 2-methyleneaziridines **8** by flash chromatography failed completely. During the high vacuum distillation of the 1:1 mixture of **8a** and **9a**, a small portion (∼5−10%) of *N*-benzylidene-1-propenylamine (mixture of *E*- and *Z*-isomers) was isolated in a few cases. Although speculative, this 2-aza-1,3-diene could originate from rupture of the N−C(2) bond of **8a** followed by isomerization into the putative *N*-allenyl-*N*-benzylamine, which subsequently can tautomerize to a 1-azadiene and further isomerize into the more conjugated 2-azadiene.

Some efforts were performed to functionalize or transform 2-methyleneaziridines **8**. However, the peculiar nature of these strained cyclic enamines prevented them of giving defined reaction products from reactions with *m*-chloroperbenzoic acid in dichloromethane (−50 °C → rt), acetone cyanohydrin in dichloromethane with or without the presence of catalytic amounts of potassium *tert*-butoxide (rt or Δ), diazomethane in ether with or without palladium catalysis (rt), *N*-chlorosuccinimide in carbon tetrachloride (−20 °C → rt) or chlorosulfonyl isocyanate in ether (−30 °C → rt). No reaction product

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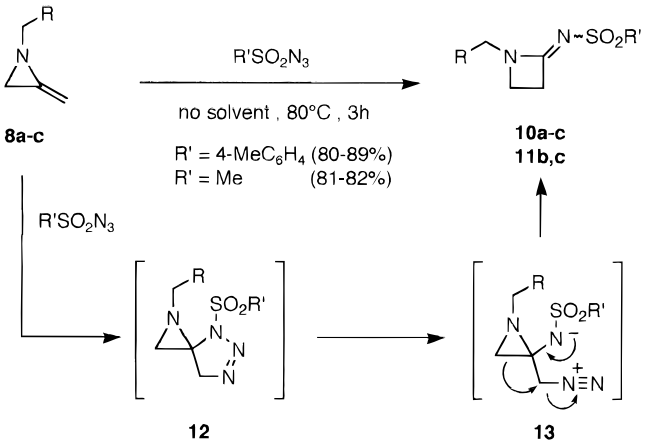
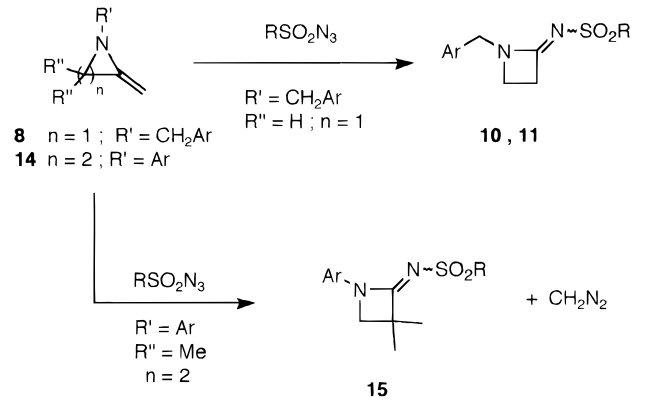
Scheme 3



Scheme 4



could be characterized from these reactions. The known ring expansion of 1-isopropyl-2-methyleneaziridine, as the sole example, with phenyl azide and azides carrying electron-withdrawing groups to give 2-iminoazetidines[13,14] is a useful process for the synthesis of β-lactam derivatives. Also the new *N*-arylmethyl- 2-methyleneaziridines **8**, described in the present paper, underwent a smooth and clean ring expansion via the spirotriazoline **12** and zwitterion **13** into 2-(sulfonylimino)azetidines **10** and **11** when reacted with *p*-toluenesulfonyl azide or methanesulfonyl azide, respectively (Scheme 3). The reaction is best performed neat at 80 °C for 3 h affording crude β-lactam derivatives **10** and **11** in almost quantitative yield. Pure samples of 1-(arylmethyl)-2-(tosylimino)-azetidines **10** and **11** were obtained after column chromatography with dichloromethane over alumina (80−89% isolated yield). Substantial decomposition of **10** and **11** occurred during flash chromatography over silica gel. Compounds **10** and **11** occurred as one geometrical isomer across the imino bond (^{1}H NMR), but the stereochemistry was not determined.

The ring expansion of **8** with sulfonyl azides demonstrates the sharp contrast with the conversion of their homologues **14**, *i.e.* 2-methyleneazetidines **14**, with the same sulfonyl azides to give 2-sulfonyliminoazetidines **15** (Scheme 4). In the latter case, the intermediate spirotriazoline underwent expulsion of diazomethane instead of ring expansion.[22]

Experimental Section

^{1}H NMR spectra were recorded either at 60 MHz or at 270 MHz, while ^{13}C NMR spectra were run at 20 MHz or 68 MHz. The type of carbon was determined either by the DEPT mode or by off resonance decoupled spectra. Mass spectra were measured at 70 eV using a GC-MS coupling or a direct inlet system. Gas chromatographic analyses were performed using a capillary column (fused silica, 20 m, glass capillary column, i.d. 0.53 mm, H_2 carrier gas) or a packed column (5−10% SE-30, Chromosorb W60−80, 1.5 m, H_2 carrier gas).

Synthesis of *N*-Arylidene-2-propenylamines. A mixture of 0.1 mol of the appropriate aromatic aldehyde **5** in 100 mL of dichloromethane was treated with 0.11 mol of allylamine and 13 g of magnesium sulfate. The mixture was magnetically stirred at room temperature for 1 h and then filtered. After evaporation of the solvent the *N*-allyl aldimines were distilled *in vacuo*: *N*-benzylideneallylamine (84% yield), bp 41−47 °C/0.04 mmHg; *N*-(4-methylbenzylidene)allylamine (86% yield), bp 68−73 °C/0.05 mmHg; *N*-(4-chlorobenzylidene)allylamine (90% yield), bp 62−78 °C/0.08 mmHg; *N*-(2,2-dimethyl-3-phenyl-1-propylidene)allylamine (92% yield), bp 70−76 °C/0.05 mmHg. All aldimines were characterized by ^{1}H NMR and IR affording spectral data in agreement with their structure. The purity of these aldimines was checked by GC (>98%).

Synthesis of *N*-Arylidene-2,3-dibromopropylamines 6. A stirred and cooled (0 °C) solution of 0.1 mol of *N*-arylideneallylamine in 150 mL of dry dichloromethane (freshly distilled from calcium hydride) was treated dropwise with a solution of 0.103 mol of bromine in 30 mL of dichloromethane. After complete addition, stirring was continued at 0 °C for 30 min and the solvent was then evaporated *in vacuo* to afford the labile *N*-arylidene-2,3-dibromopropylamines **6** in quantitative yield (purity > 95%). Attempted vacuum distillation resulted in total decomposition. These dibromoaldimines **6** were used as such in the next cyclization step.

***N*-Benzylidene-2,3-dibromopropylamine (6a)**: ^{1}H NMR (60 MHz, CCl_4) δ 3.88 (2H, d, J = 6.8 Hz); 4.0−4.2 (2H, m); 4.2−4.7 (1H, m); 7.3−7.6 (3H, m); 7.6−7.9 (2H, m); 8.33 (1H, s, br). ^{13}C NMR (20 MHz, $CDCl_3$) δ 34.0 (t, CH_2Br); 51.1 (d, CHBr); 64.0 (t, CH_2N); 128.3 and 128.5 (each d, C_{meta} and C_{para}); 131.0 (d, C_{ortho}); 135.6 (s, C_{quat}); 163.6 (d, CH=N). IR (NaCl): 1645 cm^{-1} (C=N). MS *m*/*z* (relative intensity): 303/5/7 (M^+; 1); 224/6(24); 169/71(2); 149(9); 145(7); 144(12); 121(5); 119(12); 118(100); 117(10); 106(5); 105(7); 104(15); 92(7); 91(86); 90(12); 89(12); 77(19); 76(5); 65(7); 63(5); 58(5); 57(5); 51(14); 50(7); 44(3); 43(5); 41(33).

***N*-(4-Methylbenzylidene)-2,3-dibromopropylamine (6b)**: ^{1}H NMR (60 MHz, CCl_4) δ 2.39 (3H, s); 3.87 (2H, d, J = 6.4 Hz); 4.07 (2H, d, J = 4.4 Hz); 4.2−4.7 (1H, m); 7.23 and 7.69 (4H, each d, J = 8 Hz); 8.28 (1H, s, br). ^{13}C NMR (20 MHz, $CDCl_3$) δ 21.4 (q, Me); 34.1 (t, CH_2Br); 51.3 (d, CH_3); 64.1 (t, CH_2N); 128.3 and 129.2 (each d, C_{arom}); 133.1 (s, *C*C=N); 141.2 (s, *C*-Me); 163.5 (d, CH=N). IR (NaCl): 1646 cm^{-1} (C=N). MS *m*/*z* (relative intensity): 317/19/21 (M^+, 4); 238/40 (−Br, 33); 158(6); 132(100); 119(4); 118(8); 117(12); 105(75); 103(8); 91(16); 79(4); 78(4); 77(10); 65(12); 51(4); 41(12).

***N*-(4-Chlorobenzylidene)-2,3-dibromopropylamine (6c)**: ^{1}H NMR (60 MHz, CCl_4) δ 3.93 (2H, d, J = 7.2 Hz); 4.1−4.3 (2H, m); 4.3−4.8 (1H, m); 7.52 and 7.84 (each 2H, each d, J = 8.8 Hz); 8.40 (1H, s, br). ^{13}C NMR (20 MHz, $CDCl_3$) δ 33.9 (t, CH_2Br); 50.6 (d, CHBr); 63.3 (t, CH_2Br); 129.1 and 130.1(d; C_{arom}); 130.8 and 137.9 (s, C_{quat}); 163.3 (d, CH=N). IR (NaCl): 1648 cm^{-1} (C=N). MS *m*/*z* (relative intensity): 337/39/41/43 (M^+; 10); 263(10); 262(21); 259/61(12); 258/60(42); 179(12); 155(15); 154(49); 153(30); 152(100); 151(16); 140(12); 138(21); 128(12); 127(45); 126(22); 125(84); 124(15); 121(15); 119(16); 117(14); 116(12); 111(17); 102(14); 90(18); 89(34); 76(15); 75(21); 63(17); 51(15); 50(14); 41(36).

***N*-(2,2-Dimethyl-3-phenyl-1-propylidene)-2,3-dibromopropylamine (6d)**: ^{1}H NMR (60 MHz, $CDCl_3$) δ 1.03 (6H, s); 2.70 (2H, s); 3.6−3.9 (4H, m); 4.1−4.5 (1H, m); 6.9−7.3 (5H, m); 7.56 (1H, t, J = 1 Hz). ^{13}C NMR (20 MHz, $CDCl_3$) δ 24.6 (q, Me_2); 34.0 (t, CH_2Br); 40.4 (s, *C*Me_2); 46.1 (t, Ar*C*H_2); 51.2 (d, CHBr); 63.6 (t, CH_2N); 126.1 (d, C_{ortho}); 127.7 and 130.3 (each d, C_{para} and C_{meta}); 137.7 (s, C_{quat}); 174.6 (d, CH=N). IR (NaCl): 1670 cm^{-1} (C=N). MS *m*/*z* (relative intensity): 359/61/63 (M^+; 15); 344/46/48(55); 280/2(15); 199/01/03(10); 186(25); 174(20); 145(30); 144(30); 129(20); 91(100).

Synthesis of 2-(Bromomethyl)aziridines 7a−d. A stirred solution of 0.1 mol of *N*-arylidene-2,3-dibromopropylamine **6**

in 300 mL of absolute methanol was treated portionwise with 0.3 mol of sodium borohydride. After the vigorous reaction ceased, the solution was refluxed for 2 h. The cooled solution was then poured in 500 mL of water, and extraction was performed three times with dichloromethane. The combined extracts were dried ($MgSO_4$) and evaporated *in vacuo* to give an oil, which consisted mainly of 2-(bromomethyl)aziridine **7** (>95%). Purification was performed by vacuum distillation affording pure compounds **7** (>98%; ^{1}H NMR, GC).

1-Benzyl-2-(bromomethyl)aziridine (7a): bp 72−75 °C/0.05 mmHg. ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.64 (1H, d, J = 6.27 Hz); 1.81 (1H, d, J = 3.30 Hz); 1.91−2.00 (1H, m); 3.26−3.35 (2H, m); 3.41 and 3.58 (each 1H, each d, J = 13.19 Hz); 7.26−7.37 (5H, m). ^{13}C NMR (20 MHz, $CDCl_3$) δ 35.3 (t, CH_2-Br); 39.9 (d, CHN); 63.8 (t, Ar*C*H_2N); 126.9 (C_{para}); 127.9 and 128.1 (d, C_{ortho} and C_{meta}); 138.5 (s, C_{quat}). IR (NaCl): 1496, 1455, 1357, 1223, 1157 cm^{-1}. MS *m*/*z* (relative intensity): 225/7 (M^+, 1); 146 (M^+ − Br, 33); 91(100); 65(21); 55(10); 51(10); 44(12); 42(25). Anal. Calcd 53.12 C, 5.35 H. Found: 53.21 C, 5.43 H.

2-(Bromomethyl)-1-[(4-methylphenyl)methyl]aziridine (7b): bp 80−82 °C/0.08 mmHg. ^{1}H NMR (60 MHz, CCl_4) δ 1.3−1.9 (3H, m); 2.27 (3H, s); 2.9−3.3 (2H, m); 3.13 and 3.33 (2H, each d, AB, J = 13 Hz); 7.07 (4H, s). ^{13}C NMR (20 MHz, $CDCl_3$) δ 21.0 (q, each Me); 35.1 and 35.4 (each t, N*C*H_2CH and *C*H_2Br); 40.1 (d, N*C*H); 63.1 (t, N*C*H_2Ar); 128.0 and 129.0 (each d, C_{ortho} and C_{meta}); 135.3 (s, =*C*Me); 136.6 (s, CH_2*C*=). IR (NaCl): 1521, 1442, 1354, 1220, 1151, 1052, 1020 cm^{-1}. MS *m*/*z* (relative intensity): 239/41 (M^+, 1); 160 (M^+ − Br, 18); 105(100); 79(11); 77(11); 65(3); 55(9); 44(9); 42(3); 41(4). Anal. Calcd 55.02 C, 5.88 H. Found: 54.91 C, 5.93 H.

2-(Bromomethyl)-1-[4-(chlorophenyl)methyl]aziridine (7c). Compound **7c** decomposed during high vacuum distillation. ^{1}H NMR (60 MHz, CCl_4) δ 1.4−2.0 (3H, m); 3.1−3.3 (2H, m, C*H*$_2$Br); 3.29 and 3.47 (each 1H, each d, AB, J = 13.6 Hz); 7.27 (4H, s). ^{13}C NMR (20 MHz, $CDCl_3$) δ 35.0 (d × d, NCH_2CH); 35.7 (t, *C*H_2Br); 40.3 (d, N*C*H); 63.5 (t, N*C*H_2-Ar); 128.5 and 129.5 (each d, C_{ortho} and C_{meta}); 133.0 (s, *C*Cl); 137.1 (s, C_{quat}). IR (NaCl): 1594, 1490, 1407, 1350, 1220, 1085, 1012 cm^{-1}. MS *m*/*z* (relative intensity): 259/61 (M^+, 1); 180/2 (M^+ − Br); 125/7(100); 99(6); 90(11); 89(15); 83(4); 77(4); 75(5); 63(10); 55(16); 54(8); 51(7); 50(3); 49(6); 44(14); 42(34); 41(12). Anal. Calcd 5.38 N. Found: 5.30 N.

2-(Bromomethyl)-1-(2,2-dimethyl-3-phenylpropyl)aziridine (7d): bp 120−124 °C/0.05 mmHg. ^{1}H NMR (60 MHz, $CDCl_3$) δ 0.87 and 0.93 (each 3H, each s); 1.2−1.8 (3H, m); 1.87 and 2.25 (each 1H, each d, J = 12 Hz); 2.61 and 2.72 (each 1H, each d, J = 13 Hz); 3.1−3.5 (2H, m); 7.25 (5H, s). ^{13}C NMR (20 MHz, $CDCl_3$) δ 25.5 and 25.9 (each q, Me_2); 35.6 (t, CH_2Br); 36.2 (s, Me_2*C*); 36.5 (t, NCH_2CH); 39.7 (d, NCH$_2$*C*H); 71.0 (t, NCH_2C); 125.7 (d, C_{para}); 127.5 and 130.6 (each d, C_{ortho} and C_{meta}); 138.8 (C_{quat}). IR (NaCl): 3020 cm^{-1}. MS *m*/*z* (relative intensity): 281/83 (M^+; 2); 202(3); 150(18); 148(18); 146(15); 131(13); 117(6); 105(4); 91(51); 70(100); 56(13); 55(20); 42(73); 41(24). Anal. Calcd 59.58 C, 7.14 H; 4.96 N. Found: 59.40 C, 7.27 H; 5.09 N.

Synthesis of 2-Methyleneaziridines 8. A stirred solution of 0.05 mol of 1-(arylmethyl)-2-(bromomethyl)aziridine **7** in 100 mL of dry tetrahydrofuran was treated portionwise with 0.075 mol of potassium *tert*-butoxide. The heterogeneous mixture was stirred for 24 h at room temperature after which it was poured in 300 mL of water. Extraction was performed three times with diethyl ether, and the combined extracts were washed with 50 mL of brine, dried ($MgSO_4$), and evaporated *in vacuo* to give an oil. Vacuum distillation of the reaction mixture afforded 40−48% yield of 2-methyleneaziridines **8** and 18% of 2-(*tert*-butoxymethyl)aziridines **9a,b**. 2-(*tert*-butoxymethyl)-1-[(4-chlorophenyl)methyl]aziridine (**9c**) was isolated from the residue of distillation by flash chromatography (silica gel; ethyl acetate:hexane 1:4; R_f 0.24, yield 13%) after the corresponding 2-methyleneaziridine **8c** had been removed by vacuum distillation.

1-Benzyl-2-methyleneaziridine (8a): bp 46−54 °C/0.05 mmHg. Yield: 40%. ^{1}H NMR (60 MHz, $CDCl_3$) δ 2.06 (2H, t, J = 1 Hz); 3.66 (2H, s); 4.72 (2H, t, J = 1 Hz); 7.34 (5H, s). ^{13}C NMR (20 MHz, $CDCl_3$) δ 30.6 (t, CH_2=CCH_2N); 62.8 (t, ArCH_2N); 83.5 (t, CH_2=C); 127.3 (d, C_{para}); 128.2 and 128.4 (each d, C_{ortho} and C_{meta}); 137.0 and 138.2 (each s, C_{quat}). IR (NaCl): 1780 cm^{-1} (C=C). MS *m*/*z* (relative intensity): 145 (M^+; 11); 144(33); 117(11); 105(44); 91(100); 77(11); 65(33); 54(88); 39(16). Anal. Calcd 82.72 C, 7.64 H. Found: 82.79 C, 7.73 H.

1-Benzyl-2-(*tert*-butoxymethyl)aziridine (9a): bp 72−78 °C/0.05 mmHg. Yield: 18%. ^{1}H NMR (60 MHz, $CDCl_3$) δ 1.14 (9H, s); 1.3−2.1 (3H, m); 3.1−3.7 (4H, m); 7.29 (5H, s). ^{13}C NMR (20 MHz, $CDCl_3$) δ 27.5 (q, Me_3C); 32.3 (t, NCH_2-CH); 39.6 (d, *C*HN); 64.4 and 64.5 (each t, ArCH_2N and CH_2O); 72.9 (CO); 126.9 (d, C_{para}); 128.0 and 128.3 (each d, C_{ortho} and C_{meta}); 139.3 (s, C_{quat}). IR (NaCl): 2980, 1457, 1363, 1198, 1079, 1028 cm^{-1}. MS *m*/*z* (relative intensity): 219 (M^+; 0.5); 204(1); 189(0.5); 174(1); 163(10); 162(14); 146(33); 134(4); 133(10); 132(7); 91(92); 72(49); 65(14); 57(100); 44(7); 42(14); 41(28). Anal. Calcd 76.67 C, 9.65 H, 6.39 N. Found: 76.81 C, 9.52 H, 6.49 N.

1-[(4-Methylphenyl)methyl]-2-methyleneaziridine (8b): bp 48−52 °C/0.05 mmHg. Yield: 48%. ^{1}H NMR (270 MHz, $CDCl_3$) δ 2.09 (2H, s); 2.33 (3H, s); 3.64 (2H, s); 4.70 (2H, s); 7.14 and 7.23 (each 2H, each d, J = 7.75 Hz). ^{13}C NMR (68 MHz, $CDCl_3$) δ 21.1 (Me); 30.4 (CH_2=CCH_2N); 62.5 (Ar*C*H_2N); 83.4 (*C*H_2=C); 128.2 and 129.1 (C_{arom}); 135.1, 136.9 and 137.0 (CH_2=*C* and 2 × C_{quat}). IR (NaCl): 1777 cm^{-1} ($\nu_{C=C}$). MS *m*/*z* (relative intensity): 159 (M^+; 9); 158(11); 144(5); 131(9); 119(21); 106(11); 105(100); 104(7); 103(12); 91(12); 79(25); 78(8); 77(25); 65(11); 63(7); 54(34); 51(13); 44(5); 41(9). Anal. Calcd 82.97 C, 8.23 H. Found: 83.11 C, 8.18 H.

2-(*tert*-Butoxymethyl)-1-[(4-methylphenyl)methyl]aziridine (9b): bp 78−79 °C/0.05 mmHg. Yield: 18%. ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.17 (9H, s); 1.44 (1H, d, J = 6.26 Hz); 1.67−1.76 (2H, m); 2.32 (3H, s); 3.20 and 3.46 (each 1H, ABX, J_{AB} = 9.90 Hz, J_{AX} = J_{BX} = 5.61 Hz); 3.38 and 3.43 (each 1H, AB, J = 13.36 Hz); 7.11 and 7.25 (each 2H, each d, J = 7.76 Hz). ^{13}C NMR (68 MHz, $CDCl_3$) δ 21.1 (*Me*Ar); 27.5 (Me_3C); 32.3 (NCH_2CH); 39.5 (NCH_2CH); 64.1 (NCH_2Ar); 64.5 (CH_2O); 72.8 (CO); 127.9 and 128.9 (C_{arom}); 136.2 and 136.3 (each C_{quat}). IR (NaCl): 2971, 1361, 1252, 1232, 1197, 1080 and 1021 cm^{-1}. MS *m*/*z* (relative intensity): 233 (M^+; 0.7); 232(0.5); 218(1); 203(0.5); 202(0.5); 198(0.6); 197(0.4); 172(5); 171(9); 161(3); 160(21); 158(3); 148(3); 147(5); 146(4); 119(3); 105(76); 103(3); 91(3); 79(4); 77(4); 72(58); 57(100). Anal. Calcd 6.00 N. Found: 6.07 N.

1-[(4-Chlorophenyl)methyl]-2-methyleneaziridine (8c): bp 67−79 °C/0.01 mmHg. Yield: 40%. ^{1}H NMR (270 MHz, $CDCl_3$) δ 2.11 (2H, s, CH_2=CC*H*$_2$N); 3.63 (2H, s, ArC*H*$_2$); 4.69−4.72 (2H, m, C*H*$_2$=C); 7.89 (4H, s, C_6H_4). ^{13}C NMR (68 MHz, $CDCl_3$) δ 30.6 (C*C*H_2N); 62.0 (Ar*C*H_2N); 83.8 (*C*H_2=); 128.5 and 129.5 (C_{arom}); 133.1 and 136.7 (CH_2=*C* and 2 × C_{quat}). IR (NaCl): 1779 cm^{-1} ($\nu_{C=C}$). MS *m*/*z* (relative intensity): 179/81 (M^+; 17); 178/80(28); 151/3(13); 139/41(41); 140(7); 125/7(63); 126(11); 103(15); 99(11); 90(9); 89(29); 77(6); 75(8); 62(11); 54(100); 51(7). Anal. Calcd 7.80 N. Found: 7.73 N.

2-(*tert*-Butoxymethyl)-1-[(4-chlorophenyl)methyl]aziridine (9c). Isolated by flash chromatography using silica gel, ethyl acetate:hexane 1:4; R_f 0.24. Yield: 13%. ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.18 (9H, s, Me_3); 1.45 (1H, d, J = 6.11 Hz, H_b); 1.69−1.78 (2H, m, H_a and H_c); 3.29 and 3.38 (each 1H, ABX, J_{AB} = 10.01 Hz, J_{AX} = 5.62 Hz, J_{BX} = 4.64 Hz, CH_2O); 7.28 and 7.34 (each 2H, each d, J = 8.42 Hz, C_6H_4). ^{13}C NMR (68 MHz, $CDCl_3$) δ 27.5 (Me_3); 32.1 (CH*C*H_2N); 39.8 (CHN); 63.4 and 64.4 (ArCH_2N and CH_2O); 72.9 (CO); 128.2 and 129.2 (C_{arom}); 132.6 and 137.8 (each C_{quat}). IR (NaCl): 2975, 1493, 1365, 1196, 1081, 910 cm^{-1}. MS *m*/*z* (relative intensity): 253/7 (M^+; 0.5); 196/8 (M^+ − 57, 17); 197(8); 180/2(28); 181(5); 167(9); 166(6); 127(22); 126(8); 125(60); 89(10); 72(57); 58(7); 57(100); 55(5); 44(9); 42(13); 41(28). Anal. Calcd 5.53 N. Found: 5.66 N.

1-(2,2-Dimethyl-3-phenylpropyl)-2-methyleneaziridine (8d): bp 61−65 °C/0.06 mmHg. Yield: 46%. ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.87 (6H, s); 2.02 (2H, s); 2.22 (2H, s); 2.58 (2H, s); 4.57−4.58 (2H, m); 7.07−7.22 (5H, m). ^{13}C NMR (68 MHz, $CDCl_3$) δ 25.4 (Me_2); 32.2 (NCH_2C=CH_2); 36.0 (*C*Me_2); 46.3 ($CH_2C_6H_5$); 70.2 (NCH_2CMe_2); 81.8 (CH_2=C); 125.8 (C_{para}); 127.7 and 130.6 (C_{ortho} and C_{meta}); 137.2 and 138.9

(each C_{quat}). IR (NaCl): 1779 cm^{-1} ($\nu_{C=C}$). MS *m/z* (relative intensity): 201 (M^+; 3); 200(5); 186(5); 158(3); 144(7); 131(8); 117(9); 115(6); 110(5); 109(4); 105(12); 91(85); 77(7); 70(9); 69(70); 68(47); 65(22); 63(5); 56(11); 55(20); 54(13); 53(6); 51(10); 44(6); 43(12); 42(30); 41(100). Anal. Calcd 83.53 C, 9.51 H, 6.96 N. Found: 83.31 C, 9.70 H, 7.10 N.

2-(*tert*-Butoxymethyl)-1-(2,2-dimethyl-3-phenylpropyl)aziridine (9d). Isolated by flash chromatography using silica gel, ethyl acetate:hexane 1:9, R_f 0.22. Yield: 16%. ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.96 (6H, s); 1.21 (9H, s); 1.29 (1H, d, J = 6.27 Hz); 1.55−1.58 (1H, m); 1.65 (1H, d, J = 3.30 Hz); 1.91 and 2.26 (each 1H, each d, J = 12.04 Hz); 2.65 (2H, s, NCH_2C); 3.23 (1H, d × d, J = 9.65 Hz, J_2 = 5.77 Hz); 3.48 (1H, d × d, J_1 = 9.65 Hz, J_2 = 5.77 Hz); 7.16−7.28 (5H, m). ^{13}C NMR (68 MHz, $CDCl_3$) δ 25.5 and 25.6 (Me_2); 27.6 (Me_3); 32.5 (NCH*C*H_2); 36.4 (Me_2*C*); 40.0 (NCH); 46.4 (Ar*C*H_2); 64.9 (CH_2O); 71.9 (N*C*H_2C); 72.9 (CO); 125.7 (C_{para}); 127.6 and 130.8 (C_{ortho} and C_{meta}); 139.3 (C_{quat}). IR (NaCl): 1467, 1450, 1382, 1360, 1191, 1075 cm^{-1}. MS *m/z* (relative intensity): 275 (M^+; 43); 260(4); 218(3); 204(3); 189(8); 188(52); 160(7); 146(11); 143(5); 142(11); 132(8); 131(19); 128(13); 117(12); 115(7); 113(9); 105(14); 91(71); 86(100); 84(12); 72(7); 70(59); 69(14); 68(10); 65(14); 58(12); 57(86); 56(45); 55(32); 54(6); 44(60); 43(41); 42(52); 41(66). Anal. Calcd 5.09 H. Found: 4.98 N.

1-Benzyl-2-(*tert*-pentoxymethyl)aziridine (9e). Isolated by flash chromatography using silicagel, ethyl acetate:hexane 1:9, R_f 0.16. Yield: 21%. ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.85 (3H, t, J = 7.42 Hz); 1.12 (6H, s); 1.47 (2H, q, J = 7.42 Hz); 1.49 (1H, d, 6.27 Hz); 1.72 (1H, d, J = 3.63 Hz); 1.72−1.80 (1H, m); 3.19 and 3.42 (each 1H, each d × d, J_1 = 9.73 Hz, J_2 = 5.61 Hz); 3.43 and 3.50 (each 1H, each d, J = 13.86 Hz); 7.26−7.65 (5H, m). ^{13}C NMR (68 MHz, $CDCl_3$) δ 8.2 (*Me*CH_2); 25.0 and 25.1 (Me_2C); 32.3 and 32.5 (CH*C*H_2N and *C*H_2Me); 39.6 (CHN); 64.1 and 64.3 (Ar*C*H_2N and CH_2O); 74.9 (CO); 126.9 (C_{para}); 128.0 and 128.3 (C_{ortho} and C_{meta}); 139.3 (C_{quat}). IR (NaCl): 1463, 1454, 1361, 1179, 1161, 1080 cm^{-1}. MS *m/z* (relative intensity): no M^+; 204 (M^+ − Et; 1); 164(6); 163(5); 162(13); 146(14); 133(5); 132(5); 91(100); 72(37); 71(41); 70(8); 65(16); 55(21); 54(5); 51(5); 44(10); 43(65); 42(23); 41(21). Anal. Calcd 6.00 N. Found: 5.89 N.

Synthesis of 1-(Arylmethyl)-2-(*N*-sulfonylimino)azetidines 10 and 11. A mixture of 0.001 mol of 2-methyleneaziridine **8** and 0.001 mol of *p*-toluenesulfonyl azide or methanesulfonyl azide was heated neat at 80 °C during 3 h during which nitrogen evolved. The cold reaction mixture was chromatographed over alumina using dichloromethane as eluent affording pure 2-iminoazetidines **10** or **11** in 80−89% yield.

1-Benzyl-2-[*N*-(*p*-toluenesulfonyl)imino]azetidine (10a): R_f (Al_2O_3, CH_2Cl_2): 0.39. Yield: 89%. ^{1}H NMR (60 MHz, $CDCl_3$) δ 2.40 (3H, s); 3.27 (2H, t, J = 3.7 Hz); 3.50 (2H, t, J = 3.7 Hz); 4.41 (2H, s); 7.27 (5H, s); 7.26 and 7.83 (each 2H, each d, J = 8 Hz). ^{13}C NMR (20 MHz, $CDCl_3$) δ 21.4 (q, Me); 33.3 (t, *C*H_2CH$_2$N); 45.6 (t, CH_2*C*H_2N); 48.0 (Ar*C*H_2N); 126.4, 128.1, 128.4, 128.9 and 129.3 (each d, C_{arom}); 133.4 and 140.2 and 142.4 (s, C_{quat}); 168.8 (s, C═N). IR (NaCl): 1630 cm^{-1} (C═N). MS *m/z* (relative intensity): 314 (M^+; 9); 159(18); 155(21); 149(21); 91(100); 71(9); 70(11); 65(18); 57(18); 55(7); 43(23); 41(35). Anal. Calcd 8.91 N. Found: 8.99 N.

1-[(4-Methylphenyl)methyl]-2-[*N*-(*p*-toluenesulfonyl)-imino]azetidine (10b): R_f (Al_2O_3, CH_2Cl_2): 0.38. Yield 83%; mp = 112 °C. ^{1}H NMR (270 MHz, $CDCl_3$) δ 2.33 (3H, s); 2.42 (3H, s); 3.30 (2H, t, J = 3.63 Hz); 3.46 (2H, t, J = 3.80 Hz); 4.37 (2H, s); 7.09 and 7.13 (each 2H, each d, J = 8.24 Hz); 7.28 and 7.82 (each 2H, each d, J = 8.24 Hz). ^{13}C NMR (68 MHz, $CDCl_3$) δ 21.1 and 21.5 (each Me); 33.3 (*C*H_2C═H); 45.3 (CH_2*C*H_2N); 47.8 (Ar*C*H_2N); 126.5, 128.5, 129.3, 129.6 (C_{arom}); 130.8, 138.1, 140.2, and 142.4 (C_{quat}); 168.6 (C═N). IR (KBr): 1613 cm^{-1} (C═N). MS *m/z* (relative intensity): 328 (M^+; 12); 327(4); 312(8); 264(13); 263(7); 174(11); 173(67); 157(7); 156(7); 155(33); 145(8); 133(7); 132(21); 120(9); 118(9); 106(11); 105(100); 104(7); 103(7); 92(11); 91(75); 79(11); 77(11); 65(17); 43(13); 42(7). Anal. Calcd 8.53 N. Found: 8.43 N.

1-[(4-Chlorophenyl)methyl]-2-[*N*-(*p*-toluenesulfonyl)-imino]azetidine (10c): R_f (Al_2O_3, CH_2Cl_2): 0.30. Yield 80%; mp = 137 °C. ^{1}H NMR (270 MHz, $CDCl_3$) δ 2.42 (3H, s); 3.32 (2H, t, J = 3.80 Hz); 3.50 (2H, t, J = 3.80 Hz); 4.38 (2H, s); 7.28−7.33 (4H, m); 7.15 and 7.80 (each 2H, each d, J = 8.25 Hz). ^{13}C NMR (68 MHz, $CDCl_3$) δ 21.5 (Me); 33.5 (*C*H_2CH$_2$N); 45.7 (CH_2*C*H_2N); 47.4 (Ar*C*H_2N); 126.4, 129.1, 129.4 and 129.9 (C_{arom}); 132.6, 134.2, 140.1, and 142.6 (C_{quat}); 168.8 (C═N). IR (KBr): 1614 cm^{-1} (C═N). MS *m/z* (relative intensity): 348/50 (M^+; 6); 285(7); 194/6(18); 186(9); 156(29); 145(9); 144(8); 125/7(40); 92(15); 91(100); 89(13); 86(25); 84(41); 65(97); 57(16); 51(15); 49(63); 44(15); 43(25); 42(11); 41(18). Anal. Calcd 8.03 N. Found: 8.11 N.

1-[(4-Methylphenyl)methyl]-2-(*N*-(methanesulfonyl)-imino]azetidine (11b): R_f (Al_2O_3, CH_2Cl_2): 0.35. Yield: 82%. ^{1}H NMR (270 MHz, $CDCl_3$) δ 2.36 (3H, s); 3.00 (3H, s); 2.33 (2H, t, J = 3.80 Hz); 3.50 (2H, t, J = 3.63 Hz); 4.38 (2H, s); 7.14 and 7.18 (each 2H, each d, J = 8.25 Hz). ^{13}C NMR (68 MHz, $CDCl_3$) δ 21.1 (*Me*Ar); 33.3 (C*H*$_2$C═N); 42.4 (*Me*SO_2); 45.5 (CH_2*C*H_2N); 47.8 (Ar*C*H_2N); 128.4 and 129.7 (C_{arom}); 130.8 and 138.2 (C_{quat}); 168.3 (C═N). IR (NaCl): 1632 cm^{-1} (C═N). MS *m/z* (relative intensity): 252 (M^+; 15); 251(7); 237(9); 213(11); 173(25); 145(9); 132(13); 129(10); 120(11); 118(7); 106(13); 105(100); 104(7); 103(10); 91(9); 85(7); 83(7); 81(7); 79(19); 77(17); 72(7); 71(8); 70(8); 69(7); 57(12); 56(8); 55(17); 43(84); 42(11); 41(13). Anal. Calcd 11.10 N. Found: 11.20 N.

1-[(4-Chlorophenyl)methyl]-2-[*N*-(methanesulfonyl)-imino]azetidine (11c): R_f (Al_2O_3, CH_2Cl_2): 0.38. Yield: 81%; mp = 64 °C. ^{1}H NMR (270 MHz, $CDCl_3$) δ 3.00 (3H, s); 3.34 (3H, t, J = 3.63 Hz); 3.56 (2H, t, J = 3.63 Hz); 4.41 (2H, s, C*H*$_2$Ar); 7.22 and 7.35 (each 2H, each d, J = 8.25 Hz). ^{13}C NMR (68 MHz, $CDCl_3$) δ 33.4 (*C*H_2C═N); 42.3 ($MeSO_2$); 45.8 (CH_2*C*H_2N); 47.3 (Ar*C*H_2N); 129.2 and 129.8 (C_{arom}); 132.6 and 134.1 (C_{quat}); 168.5 (C═N). IR (KBr): 1630 cm^{-1} (C═N). MS *m/z* (relative intensity): no mass spectrum could be obtained using the direct inlet system or GC-MS analysis (decomposition). Anal. Calcd 10.27 N. Found: 10.15 N.

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