Supporting Information

Direct observation and characterisation of 3-azido-2H-azirines: postulated, but highly elusive intermediates

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[1] General Information

**IR spectra** were measured on a FT-IR Spectrometer *IFS 28* from BRUKER or on *Nicolet iS5* from THERMO FISCHER SCIENTIFIC. Spectra were measured in suitable organic solvents and are reported in cm$^{-1}$ in decreasing order of wavenumber ($\tilde{\nu}$).

**NMR spectra** were measured on a *UNITY INOVA 400* FT spectrometer from VARIAN. $^1$H NMR spectra were measured at 400 MHz and $^{13}$C NMR at 100 MHz. NMR signals were referenced to TMS ($\delta = 0$) or solvent signals and recalculated relative to TMS. DEPT 135 and 2D NMR methods, such as gHSQCAD, etc. were used for assignment of signals, when necessary. Multiplicities of the signals are reported using the standard notations: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br. s = broad singlet, etc.

**In situ IR spectra** were recorded in real time using a *ReactIR 15* spectrometer (manufactured by METTLER TOLEDO) equipped with a *DS AgX Fiber SiComp* probe.

**Mass spectra** were obtained from *micrOTOF QII* spectrometer from BRUKER utilizing electrospray-ionisation technique (ESI).

**Quantitative elementary analyses** were performed on a *Vario Micro Tube* from ELEMENTAR ANALYSENSYSTEME GMBH HANAU.

**Thin layer chromatography** was performed using *Macherey-Nagel Polygram SIL G/UV$_{254}$ foils*.

**Flash chromatography** was performed with Silica gel 60 M (particle-size 0.04–0.063 mm) as the stationary phase from the company *Macherey-Nagel*.

**Photolysis** experiments were performed utilising a high-pressure Hg-lamp (*TQ 150, Heraeus, Hanau, Germany*).

*NOTE:* Compounds 1, 4, 11 and 12 should be considered highly explosive, and effective safety measures, such as utilisation of blast-shield, thick hand-gloves, etc., must be taken. Special precautions should be taken during the removal of solvents to obtain these compounds in pure state. We highly recommend the use of only dilute solutions, in preferably high boiling solvents.
[2] Experimental procedures

[2a] Synthesis of diazide 1:

\[
\text{N}_3\text{CN} \quad \text{N}_3\text{CO}_2\text{Me}
\]

Diazide 1 was synthesised utilising a literature known procedure.Compound 1 was dissolved in dichloromethane to avoid any untoward incident which is highly possible when handling it in pure state. Generally, 1 mL of this dichloromethane solution had 30 mg of diazide 1 dissolved in it. This diazide was found to be stable even when the above solution was kept in refrigerator (−23 °C) for 15 days. The NMR spectra were in accordance with those published in literature.

\[\text{H NMR (400 MHz, CDCl}_3\text{)}: \delta = 3.84 (s, CH}_3\text{).}\]

\[\text{C NMR (100 MHz, CDCl}_3\text{)}: \delta = 52.88 (q, CH}_3\text{), 80.80 (s, C(CN)CO}_2\text{CH}_3\text{), 113.31 (s, CN), 159.51 (s, C(N}_3\text{)), 162.17 (s, CO}_2\text{CH}_3\text{). Assignment for CO}_2\text{Me was confirmed by CIGAR.}\]

[2b] Synthesis of 2H-azirine 5 via photolysis of diazide 1:

\[
\text{N}_3\text{C} \quad \text{N} \quad \text{CN} \quad \text{CO}_2\text{Me}
\]

A solution of the diazide 1 (30 mg, 0.18 mmol) in CDCl₃ (0.75 mL) was photolysed, in a normal glass NMR tube, utilising a high-pressure Hg-lamp (λ > 320 nm) at −60 °C for 1 h, and subsequently, NMR measurement at the same temperature indicated the complete consumption of diazide 1 and the formation of azirine 5 in 78% yield (1H NMR).

\[\text{H NMR (400 MHz, CDCl}_3\text{)}: \delta = 3.92 (s, CH}_3\text{).}\]

\[\text{C NMR (100 MHz, CDCl}_3\text{)}: \delta = 32.78 (s, C(CN)CO}_2\text{CH}_3\text{), 54.94 (q, CH}_3\text{), 114.46 (s, CN), 150.12 (s, CN}_3\text{), 164.32 (s, CO}_2\text{CH}_3\text{). Assignment for CO}_2\text{Me was confirmed by CIGAR.}\]

[2c] Synthesis of cycloaddition product 9:

\[
\text{N} \quad \text{N} \quad \text{N} \quad \text{CN} \quad \text{CO}_2\text{Me}
\]

A solution of diazide 1 (30 mg, 0.18 mmol) in CDCl₃ (0.75 mL) was photolysed, utilising the procedure mentioned in 2b, at −60 °C, and subsequently, the probe was analysed by low-temperature NMR spectroscopy for the complete formation of azirine 5. Subsequently, cyclooctyne (4 μL, mmol) was added at −60 °C and the formation of the trapping product 9 could also be seen in the 1H NMR
spectrum. Then, the NMR probe was warmed to −20 °C, and more cyclooctyne (4 µL, mmol) was added. At last, the probe was further warmed to −10 °C, and an additional amount of cyclooctyne (12 µL, mmol) was added. This resulted in the complete disappearance of the signals of azirine 5, and only the signals of 1H-1,2,3-triazole 9 could be observed. All together 20 µL of cyclooctyne was added, in a time span of 45 min, to the NMR probe to obtain complete reaction. This solution of cycloaddition product 9 was then warmed to RT, and cyclooctyne as well as CDCl$_3$ were removed under high-vacuum, thereby, yielding compound 9, as a straw coloured oil in 57% yield. Triazole 9 was found not be very stable at RT and decomposition can be seen in the $^1$H NMR spectrum, which was measured at RT.

$^1$H NMR (400 MHz, CDCl$_3$): δ = 1.62 (m, 4H, 2 x CH$_2$), 1.85 (m, 2H, CH$_2$), 2.00 (m, 2H, CH$_2$), 3.05 (m, 2H, CH$_2$), 3.17 (m, 2H, CH$_2$), 3.94 (s, 3H, CH$_3$).

$^{13}$C NMR (100 MHz, CDCl$_3$): δ = 21.95 (t, CH$_2$), 24.08 (t, CH$_2$), 24.30 (t, CH$_2$), 25.02 (t, CH$_2$), 25.89 (t, CH$_2$), 27.06 (t, CH$_2$) 30.11 (s, C(CN)CO$_2$CH$_3$), 54.73 (q, CH$_3$), 113.91 (s, CN), 137.74 (s, C-9α), 146.35 (s, C-3α), 147.49 (s, NCN), 163.64 (s, CO$_2$CH$_3$).

HR-MS (ESI): m/z calcd. for C$_{26}$H$_{29}$N$_{10}$Na$_2$O$_4$ [2M + 2Na + H]$^+$ 655.3420; found: 655.3459; C$_{26}$H$_{30}$N$_{10}$Na$_2$O$_4$ [2M + 2Na + 2H]$^+$ 656.3498; found: 656.3480.


Freshly distilled chloroacetaldehyde (0.33 mL, 0.37 g, 5 mmol) was added dropwise to a solution of HN$_3$/CHCl$_3$ (10 mmol in 5 mL), maintained at −5 °C. After complete addition, the reaction mixture was allowed to warm to RT and stirred for 2 h. Subsequently, the reaction mixture was cooled to −50 °C, and all the volatiles were recondensed at ca. 0.005 mbar. The residue so obtained was α-azido alcohol 10, and it was utilised as a permanently cooled substance in the next step.

Compound 10, so obtained above, was dissolved in cold (−50 °C) CHCl$_3$ (3 mL), and to this solution was added PBr$_3$ (1.41 mL, 4.06 g, 15 mmol). This reaction mixture was stirred at this temperature for 1 h, and further 12 h at RT, and at the end, a 1:1 pentane/diethyl ether mixture (25 mL) was added. The resulting solution was washed first with distilled water (25 mL) and subsequently with brine (25 mL). The organic phase was dried over MgSO$_4$, and the solvent was removed in vacuo leading to a transparent liquid 11 (48%; based on chloroacetaldehyde).

$^1$H NMR (400 MHz, CDCl$_3$): δ = 3.81 (dd, $^3$J = 11.7 Hz, $^2$J = 9.0 Hz, 1H, 2-Hα), 3.92 (dd, $^2$J = 11.7 Hz, $^3$J = 3.6 Hz, 1H, 2-Hb), 5.70 (dd, $^3$J = 9.0 Hz, 3.6 Hz, 1H, CH).

$^{13}$C NMR (100 MHz, CDCl$_3$): δ = 46.60 (t, CH$_3$), 66.80 (d, CH).
[2e] Synthesis of 1H-1,2,3-triazole 13: trapping reaction with cyclooctyne

![Image of 1H-1,2,3-triazole 13]

To a solution of compound 11 (0.92 g, 5.0 mmol) in distilled n-hexane (5 mL), maintained at −20 °C, was added, dropwise, a solution of cyclooctyne (0.87 g, 7 mmol, 1.4 eq) in distilled n-hexane (5 mL), and the reaction mixture was stirred for 1 h at this temperature. Subsequently, the solvent was removed in vacuo, and the crude product was purified by flash chromatography over silica-gel (CH₂Cl₂/Et₂O 10:1). 1H-1,2,3-triazole 13 was obtained as a white solid in 93% yield.

mp: 79−81 °C

¹H NMR (400 MHz, CDCl₃): δ = 1.37−1.50 (m, 4H, CH₂), 1.68−1.78 (m, 2H, CH₂), 1.78−1.95 (m, 2H, CH₂), 2.75 (m, 2H, CH₂), 2.91 (t, ³J = 6.4 Hz, 2H, CH₂), 4.28 (dd, ²J = 11.6 Hz, ³J = 4.4 Hz, 1H, CH₂Cl), 4.88 (dd, ²J = 11.6 Hz, ³J = 10.4 Hz, 1H, CH₂Cl), 6.21 (dd, ²J = 10.4 Hz, 4.4 Hz, 1H, CH).

¹³C NMR (100 MHz, CDCl₃): δ = 21.44 (t, CH₂), 24.43 (t, CH₂), 24.57 (t, CH₂), 25.90 (t, CH₂), 25.96 (t, CH₂), 28.20 (t, CH₂), 45.13 (t, CH₂), 54.43 (d, CH), 134.07 (s, C-9α), 145.53 (s, C-3α).

Anal. calcd. for C₁₀H₁₅BrClN₃ (292.60): C, 41.05; H, 5.17; N, 14.36; found: C, 41.25; H, 5.21; N, 14.55.

HR-MS (ESI): m/z calcd. for C₁₀H₁₆⁷¹Br⁴⁵ClN₃ [M + H]⁺ 294.0189; found: 294.0188.

[2f] Synthesis of 1,1-diazido-2-chloroethane (12):

![Image of 1,1-diazido-2-chloroethane 12]

To a solution of 1-azido-1-bromo-2-chloroethane (11) (802 mg, 4.35 mmol) in anhydrous CHCl₃ (5 mL) was added, at 0 °C, a solution of tetramethylguanidinium azide (TMGA; 1.58 g, 10 mmol, 2.3 eq) in 5 mL anhydrous CHCl₃. The mixture was allowed to warm to RT and stirred for 12 h. Subsequently, the solvent was removed in vacuo, and the crude product was carefully purified by flash chromatography (SiO₂; Et₂O), yielding diazide 12 as a transparent liquid in 77% yield.

¹H NMR (400 MHz, CDCl₃): δ = 3.58 (d, ³J = 6.0 Hz, 2H, CH₂), 4.89 (t, ³J = 6.0 Hz, 1H, CH).

¹³C NMR (100 MHz, CDCl₃): δ = 44.71 (t, CH₂), 76.61 (d, CH).

The characterisation of diazide 12 was limited to NMR spectroscopy owing to the highly explosive nature of this molecule. It is advised to utilise this molecule only in dilute solutions; pure 12 can lead to heavy explosions.
Synthesis of bis-1H-1,2,3-triazole 14: Trapping diazide 4 with cyclooctyne

Compound 12 (72 mg, 0.49 mmol) was dissolved in n-hexane (10 mL), and cooled to −20 °C. To this was added, dropwise, cyclooctyne (270 mg, 0.31 mL, 2.5 mmol) as a solution in 5 mL n-hexane, and the reaction mixture was stirred for 2 h. Subsequently, all the volatiles (solvent and unreacted cyclooctyne) were removed with a high-vacuum pump. The solid so obtained was recrystallised from n-hexane to yield 14 as a white solid (96%).

\[
\text{mp: 149–151 °C.}
\]

\[\begin{align*}
^1\text{H NMR (400 MHz, CDCl}_3\text{):} & \ \delta = 1.28–1.42 \text{ (m, 8H, CH}_2\text{), 1.48–1.57 \text{ (m, 4H, CH}_2\text{), 1.66–1.75 \text{ (m, 4H, CH}_2\text{), 2.79–2.89 \text{ (m, 8H, CH}_2\text{), 4.71 (d, }^3\text{J }= 7.5 \text{ Hz, 2H, CH}_2\text{Cl), 7.03 (t, }^3\text{J }= 7.5 \text{ Hz, 1H, CH).}} \\
^13\text{C NMR (100 MHz, CDCl}_3\text{):} & \ \delta = 21.16 \text{ (t, 2 x CH}_2\text{), 24.31 \text{ (t, 2 x CH}_2\text{), 24.85 \text{ (t, 2 x CH}_2\text{), 25.56 \text{ (t, 2 x CH}_2\text{), 26.63 \text{ (t, 2 x CH}_2\text{), 28.22 \text{ (t, 2 x CH}_2\text{), 41.93 \text{ (t, CH}_2\text{Cl), 71.17 \text{ (d, CH), 134.13 \text{ (s, 2 x C), 146.48 \text{ (s, 2 x C).}}} \end{align*}\]

HR-MS (ESI): m/z for \(\text{C}_{18}\text{H}_{28}\text{ClN}_6\) [M + H]^+: 363.2064; found: 363.2103; for \(\text{C}_{18}\text{H}_{27}\text{ClN}_6\text{Na} [M + Na]^+ \): 385.1910; found: 385.1883; for \(\text{C}_{18}\text{H}_{27}\text{ClN}_6\text{Na} [M + K]^+ \): 401.1623; found: 401.1645.

Synthesis of 1,1-diazidoethene (4):

Under nitrogen atmosphere, a solution of 1,1-diazido-2-chloroethane (12) (490 mg, 3.35 mmol) in anhydrous Et\(_2\)O (25 mL) was cooled to −20 °C, and KO\(_2\)Bu (790 mg, 7.0 mmol, 2.09 eq) was added very carefully in portions. After, complete addition, the reaction mixture was allowed to warm to 0 °C, and stirred for 1 h. Subsequently, the reaction mixture was diluted with anhydrous Et\(_2\)O, and filtered, and extracted with more abs. Et\(_2\)O. The organic phase was removed in vacuo only to an extent wherein small amounts of Et\(_2\)O were left, so that compound 4 remained as a solution. Attempts to completely remove the solvent led to violent explosions. A yield of 23% (\(^1\)H NMR; based on compound 12) was obtained; however, diazide 4 always remained in a solution of Et\(_2\)O and tert-butanol.

\[\begin{align*}
^1\text{H NMR (400 MHz, CDCl}_3\text{):} & \ \delta = 4.39 \text{ (s, CH}_3\text{).}} \\
^13\text{C NMR (100 MHz, CDCl}_3\text{):} & \ \delta = 85.26 \text{ (t, }^3\text{J }= 164 \text{ Hz, CH}_2\text{), 139.78 \text{ (s, C(N}_3\text{)H}_3\text{).}} \end{align*}\]

The assignment was further supported by gHSQCAD 2D NMR spectroscopic technique.
IR (CDCl$_3$; cm$^{-1}$): $\tilde{\nu}$ = 2977 (C−H), 2120 (N$_3$; asym.), 1641 (C=C), 1311 (N$_3$; sym.).

t$_{1/2}$ = 3 h 40 min (40 °C).

Owing to the highly explosive nature of diazide 4, characterisation was limited to NMR and IR spectroscopic analytical methods. The structure of this diazide was unambiguously confirmed by trapping it with cyclooctyne, as detailed in the next section.

[2i] Synthesis of bis-1H-1,2,3-triazole 15: Trapping diazide 4 with cyclooctyne

To the above obtained solution of diazide 4 taken in 10 mL distilled n-hexane, cooled to −20 °C, was added, dropwise, a solution of cyclooctyne (1.07 mL, 8 mmol, eq) in 5 mL distilled n-hexane, and the reaction mixture was stirred for 2 h. Subsequently, the solvent was removed in vacuo, and the crude product was purified by flash chromatography over silica-gel (CH$_2$Cl$_2$/Et$_2$O 10:1), to yield 15 as an oil (84%).

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 1.39–1.41 (m, 8H, CH$_2$), 1.47–1.53 (m, 4H, CH$_2$), 1.72–1.77 (m, 4H, CH$_2$), 2.48 (t, $J$ = 5.2 Hz, 4H, CH$_2$), 2.90 (t, $J$ = 5.2 Hz, 4H, CH$_2$), 5.90 (s, 2H, CH$_2$).

$^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ = 21.33 (t, CH$_2$), 24.33 (t, CH$_2$), 24.76 (t, CH$_2$), 25.75 (t, CH$_2$), 25.91 (t, CH$_2$), 27.88 (t, CH$_2$), 114.20 (t, CH$_2$), 134.24 (s, C), 134.81 (s, C), 145.52 (s, C-3a).

HR-MS (ESI): m/z calcd. for C$_{18}$H$_{27}$N$_6$ [M + H]$^+$ 327.2292; found: 327.2278; C$_{18}$H$_{26}$N$_6$Na [M + Na]$^+$ 349.2111; found: 349.2096; C$_{18}$H$_{26}$N$_6$K [M + K]$^+$ 365.1856; found: 365.1840.


The solution of 4/Et$_2$O, as obtained in section 2h, was taken in 0.7 mL CDCl$_3$ in a NMR tube, and this solution was photolysed at −55 °C using a high-pressure Hg-lamp for 30 min. Low-temperature NMR spectroscopy (−55 °C) indicated the formation of 2H-azirine 16 in a yield of 34% ($^1$H NMR; based on diazide 4).

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 2.29 (s, CH$_2$).
$^{13}$C NMR (100 MHz, CDCl$_3$): $\delta = 28.54$ (t, CH$_2$), 162.13 (s, CN$_3$).

t$_{1/2}$ = 12 min (−40 °C).

IR (CDCl$_3$; cm$^{-1}$): $\tilde{v} = 2148$ (N$_3$), 1756 (C=N).

The same reaction was also performed in toluene-d$_8$, and similarly, azirine 16 could be identified, but the reaction did not reach completion.

$^1$H NMR (400 MHz, toluene-d$_8$): $\delta = 1.49$ (s, CH$_3$).

$^{13}$C NMR (100 MHz, toluene-d$_8$): $\delta = 27.14$ (t, CH$_2$), 161.25 (s, CN$_3$).

The assignment was further supported by gHSQCAD 2D NMR spectroscopic technique.
[3] NMR Spectra

$^1$H NMR (CDCl$_3$)

Chemical shifts:
- 7.26 ppm
- 20.18 ppm
- 3.84 ppm

Structural formula:

[Diagram of the molecule with chemical shifts marked]
$^{13}$C NMR (CDCl$_3$)
$^1$H NMR
CDCl$_3$
$T = -60 \, ^\circ C$
$^{13}$C NMR
CDCl$_3$
$T = -60 \, ^\circ\text{C}$
$^13$C NMR (CDCl$_3$)
$^{13}$C NMR (CDCl$_3$)
$^1$H NMR (CDCl$_3$)
$^{13}$C NMR ($\text{CDCl}_3$)

![NMR spectrum graph]
$^1$H NMR (CDCl$_3$)
$^1$H NMR (CDCl$_3$)
$1^3\text{C NMR (CDCl}_3\text{)}$
\[
\text{N}_3\text{N} \xrightarrow{\text{hv}} \text{N}_3
\]

\(-55 ^\circ \text{C}\)

\[
\text{CDCl}_3
\]

\[\text{Et}_2\text{O}\]

\[\text{CH}_2\text{Cl}_2\]

\[\text{ppm}\]

\[162.13\]

\[28.54\]
$\text{N}_3$ $\text{N}_3$ $\xrightarrow{\text{hv}}$ \text{N}_3$

$\text{N}_3$

4 $\xrightarrow{\text{hv}}$ 16

toluene-d$_8$

$-55 \, ^\circ \text{C}$

$^1\text{H NMR (toluene-d}_8)$

$-55 \, ^\circ \text{C}$

$\delta (\text{ppm})$

4

Et$_2$O

16

Et$_2$O
$^{13}$C NMR of 16 (coupled) toluene-$d_8$
$T = -55 \, ^{\circ}C$
\[
\text{N}_3 \quad \text{hv} \quad \text{N}_3 \\
-55 ^\circ \text{C} \\
toluene-d_8 \\
\text{N}_3 \quad \text{N}_3 \\
4 \quad 16
\]
[4] Real-time monitoring of the photolysis reaction of diazide 4 by *in situ* IR (ReactIR):

\[
\begin{align*}
\text{N}_3 & \quad \xrightarrow{h\nu} \quad \text{N}_3 \\
4 & \quad \xrightarrow{-55 \degree C} \quad \text{N}_3 \\
\text{CDCl}_3 & \quad 16
\end{align*}
\]

In the IR spectra shown below, the green dotted line represents diazide 4 and the gray or red line represents the \(2H\)-azirine 16. The temperature has been varied from −55 °C to RT.