1,4-Oxazine†

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The fundamental heterocyclic compound 1,4-oxazine has been generated using FVP. It is the first parent heterocycle among all the possible isomeric oxazines, thiazines and their heavier atom analogues to be characterized spectroscopically, and is shown to exist in solution entirely as the 4H-isomer. X-ray structure determination of the N-Boc precursor shows significant deviations from theoretically predicted geometric parameters.

While six-membered ring heterocycles containing two group 15 atoms, exemplified by the three isomeric diazines, are well known, stable aromatic compounds, neutral analogues containing one or more group 16 atoms cannot be aromatic and are much less stable. For example, although both 1,4-dioxin1 and 1,4-dithiin2 were prepared at an early date, these compounds are rather unstable and highly reactive towards addition and polymerisation.1,3 Among the many possible parent six-membered ring heterocycles containing one group 15 atom and one group 16 atom, none appear to have been so far isolated or spectroscopically characterised, with the sole exception of 1,4-thiazine which was the subject of a single report in 1948,4 not subsequently reproduced.

1,4-Oxazine 1 is among the simplest heterocyclic compounds to be so far unknown. Although a fair number of substituted and ring-fused 1,4-oxazines are known, the parent compound has never been prepared and work on it has so far been restricted to theoretical predictions of bond lengths and electron distribution.5 Our long-standing interest in the area started with the unexpected formation of 1,4-dioxin in a retro-Diels–Alder reaction under conditions of flash vacuum pyrolysis (FVP), which allowed its NMR spectra to be recorded for the first time.6 However numerous attempts to extend the retro-Diels–Alder approach to formation of 1,4-oxazine by pyrolysis of derivatives 2 or 3 failed. Synthesis analogous to that of 1,4-thiazine by pyrolysis of cyclic imide 4, either with or without a reducing metal, was also unsuccessful as other processes intervened (Scheme 1).7

A breakthrough in the area occurred in 2007 when Coudert, Gillaizeau and co-workers described the three-step conversion of 4 into 6, thus making a simple monosubstituted 1,4-oxazine readily available for the first time.8 We now report the removal of the tert-butoxycarbonyl group from 6 to generate the parent 1,4-oxazine 1 together with its spectroscopic characterisation. Wasserman achieved thermal deprotection of an aliphatic N-tert-butoxycarbonyl amine in the course of a synthesis of the alkaloid homaline by boiling either in quinoline or diphenyl ether,9 and a short time later Cava extended this method to heterocyclic derivatives when he described removal of N-tert-butoxycarbonyl groups from pyrroles and indoles in almost quantitative yield simply by heating the solids at 180–185 °C.10

This suggested to us that FVP might be the ideal technique for conversion of 6 into 1: the purely thermal reaction involving no acids or bases would be further encouraged by high vacuum since two molecules of inert gaseous by-products are formed – isobutene and CO2. The experimental set-up would also produce the oxazine directly in the liquid nitrogen-cooled cold trap giving the best chance for its isolation. In a brief model study, both N-tert-butoxycarbonylpiperidine and -pyrrole behaved well giving excellent yields of deprotected products together with isobutene and CO2 at 450–500 °C and 10−2 Torr. When a sample of compound 6 was subjected to FVP at 450 °C and 10−2 Torr it gave some unreacted starting material at the

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B

S Te 177.8 6.2 1.9 177.5 5.8

B

S Se 178.8 7.7 2.0 181.2 7.7

1 protonated species.23

spectrum was obtained in TFA as solvent and so clearly refers to

1

O NH 196.9 10.8 5.2 178.4 14.0 5.2

a

This work.

b Two separate values for 6 due to restricted rotation of Boc.8

Table 1 CH coupling constants (Hz) for 1, 6 and similar compounds

<table>
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<th>X</th>
<th>Y</th>
<th>( J_{C2-H2} )</th>
<th>( J_{C2-H3} )</th>
<th>( J_{C2-H6} )</th>
<th>( J_{C3-H1} )</th>
<th>( J_{C3-H2} )</th>
<th>( J_{C3-H3} )</th>
<th>Ref.</th>
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<td>O</td>
<td>NH</td>
<td>196.9</td>
<td>10.8</td>
<td>5.2</td>
<td>178.4</td>
<td>14.0</td>
<td>5.2</td>
<td>a</td>
</tr>
<tr>
<td>O</td>
<td>N Boc</td>
<td>197.6</td>
<td>11.1</td>
<td>6.2</td>
<td>187.8</td>
<td>14.9</td>
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<td>197.2</td>
<td>16.4</td>
<td>~0</td>
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<td>16.4</td>
<td>~0</td>
<td>6</td>
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<tr>
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<td>S</td>
<td>179.2</td>
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<td>~0</td>
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<td>177.5</td>
<td>5.8</td>
<td>~0</td>
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</table>

The \(^{14}\)N NMR spectrum was also recorded showing two signals at \( \delta = -276 \) (6) and \(-325 \) (1) relative to MeNO\(_2\). These are assigned on the basis that after 6 h the signal at \(-325 \) had completely disappeared, while that at \(-276 \) remained unchanged and was shown by a 2D experiment to correlate with the \(^1\)H NMR signals for 6. We were also able to obtain a HRMS measurement.

It should be mentioned that 1,4-oxazine seems to be stabilised in solution by the presence of the unreacted precursor 6, perhaps by a hydrogen bonding interaction. FVP of 6 at temperatures of 500 °C and higher led to complete conversion to give a product which decomposed in CDCl\(_3\) before spectra could be obtained. Attempts to record the spectra of the 450 °C pyrolysis products in C\(_6\)D\(_6\) likewise led to immediate polymerisation of 1 and only signals for 6 and isobutene were detected.

Finally, in the course of the repeated preparations of 6 required for this work, the compound which Coudert and coworkers reported as a colourless oil was observed to sublime in a closed flask upon storage at \(-30 \) °C for several months to give colourless crystals, mp 35–36 °C, suitable for X-ray diffraction. The resulting structure (Fig. 2),24 the first for a monosubstituted 1,4-oxazine, shows a marked difference from the data predicted theoretically for 1,4-oxazine,1 which also has unequal bond lengths and a distinctly pyramidal nitrogen (angle sum at N: 359.8° vs. 355.5°).27

Although 1,4-oxazine 1 can now be generated and observed spectroscopically, it is not at all stable and decomposes in CDCl\(_3\) solution to give brown insoluble, probably polymeric products with a half-life at RT of about one hour.

The authors thank Dr T. Lebl for running the \(^{14}\)N NMR spectrum.

Notes and references

† Experimental procedure for generation of 4H-1,4-oxazine 1: a sample of 6 (ref. 8) (0.2 g) was volatilised through a 30 × 2.5 cm fused quartz
tube heated within a horizontal laboratory tube furnace at 450 °C and maintained at a pressure of 10⁻² Torr by a rotary oil pump. The contact time in the hot zone under these conditions was estimated to be ca. 10 ms. The products were collected in a liquid nitrogen cooled U-shaped trap and, after the pyrolysis was complete, were dissolved out in CDCl₃ for analysis. The spectra showed the presence of unchanged 6, isobutene, and 1:

\[ \delta_H (300 MHz, CDCl₃) 5.29 \text{ and } 5.19 (4H, A₂B₂ pattern, J(H-H) 4.5 Hz) \]  and 2.92 (1H, br s);

\[ \delta_C (75 MHz, CDCl₃) 126.4 (CH-O) \text{ and } 114.5 (CH-N) \];

\[ \delta_C (undecoupled) 126.4 \text{ (ddd, J = 196.9, 10.8 and 5.2 Hz)} \]  and 114.5 \text{ (ddd, J = 178.4, 14.0 and 5.2 Hz)}; HRMS (ES⁻): found 84.0462. C₄H₆NO (MH⁻) requires 84.0449.

24. CCDC 956939.