ments are needed to fully understand the intimate nature of the interactions involved. Moreover, the relevance of the result obtained with 1-octene in Brij 35—epoxidation in up to 48 % yield—must be pointed out. These results compare very well with those reported for reactions carried out with simple porphyrins,[15] which underlines the value of our system. Olefins such as 1-octene, cyclooctene, and cyclohexene could be oxidized with NaClO in homogeneous medium to give good yields of the epoxides only in the presence of polyhalogenated or tailor-made metalloporphyryns.

Finally, in the presence of micellar aggregates the catalysts showed remarkable stability toward the degradative action of NaClO. In fact, under the conditions used for the epoxidation less than 5 % degradation had occurred (UV/Vis) even after a reaction time of two days.[16]

The catalytic system reported here may be a good mimic for the enzyme-catalyzed oxidation reaction, owing to its high stability and its high degree of selectivity with regard both to the substrate and the formation of epoxides. Further studies aimed at the construction of more robust macrocycles suitable for use with stronger oxidants on a wider range of substrates are underway.

Received: August 8, 1997 [Z10786IE]
German version: *Angew. Chem.* **1998**, *110*, 1154 – 1156

Keywords: alkenes • epoxidations • micelles • porphyrinoids • selectivity

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[16] The catalysts, however, are not stable in the presence of other oxidants, namely H_2O_2 and $KHSO_5$. Oxidation reactions with iodosylbenzene (PhIO) are under investigation.

A New Tetracycle from Dimerization of the *N*-Methylpyridazinium Ion in Aqueous Solution[**]

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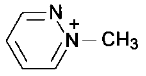
Dedicated to Professor David A. Buckingham on the occasion of his 60th birthday

During an investigation into OD^--catalyzed H – D exchange in the *N*-methylpyridazinium ion (**1**), we observed that in aqueous alkaline solution this species stereospecifically forms the tetraazafluorene **2**.[1] Despite an extensive literature



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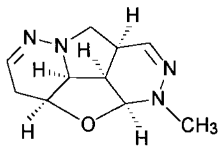

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[**] We thank Professor W. T. Robinson of the University of Canterbury for X-ray data collection.

search we could find no reference to dimerization of related *N*-alkylazinium or diazinium cations, nor has a tetracycle possessing the structural features of **2** been reported. However, 1,3-dipolar cycloaddition of acetylenic compounds to pyridazinium ylides has long been a recognized route to azaindolizines,[2] and certain *N*-ethyltriazinium ions are known to dimerize to tricyclic hexaazaphenanthrenes.[3] Remarkably, no fewer than four separate and consecutive processes are observed when dimerization of **1** is monitored with ^{1}H NMR spectroscopy (D_2O solution, 25.0 °C), and a study of these has allowed the mechanism of formation of **2** to be described in detail.

The tetracycle is rapidly formed upon treatment of **1** as its I^- or ClO_4^- salt with strong alkali at room temperature. Thus, in a one-pot synthesis, the I^- salt of **1** affords **2** in 58% recovered yield[4] when the reaction is carried out in aqueous 1M NaOH at room temperature and worked up after 15 min. The structure of **2** was initially assigned with a combination of COSY, HETCOR, and NOE spectroscopic methods and was later confirmed by X-ray crystallography. The structure of one of the four independent molecules contained in the asymmetric unit (Figure 1) shows that the all-*cis* ring junctions result in a molecule with a well-defined cavity (diameter ca. 4 Å, depth 2 Å). All hydrogen atoms except those of the CH_3 group lie on the exterior surface of the molecule.

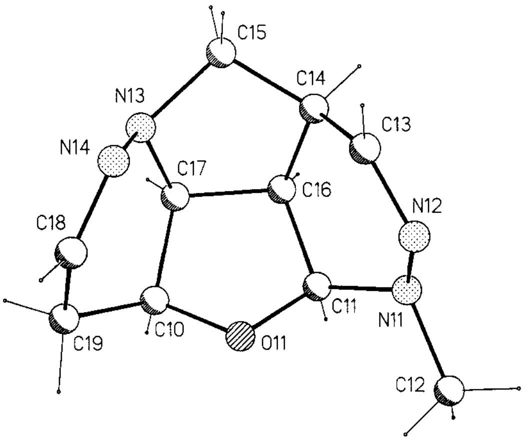
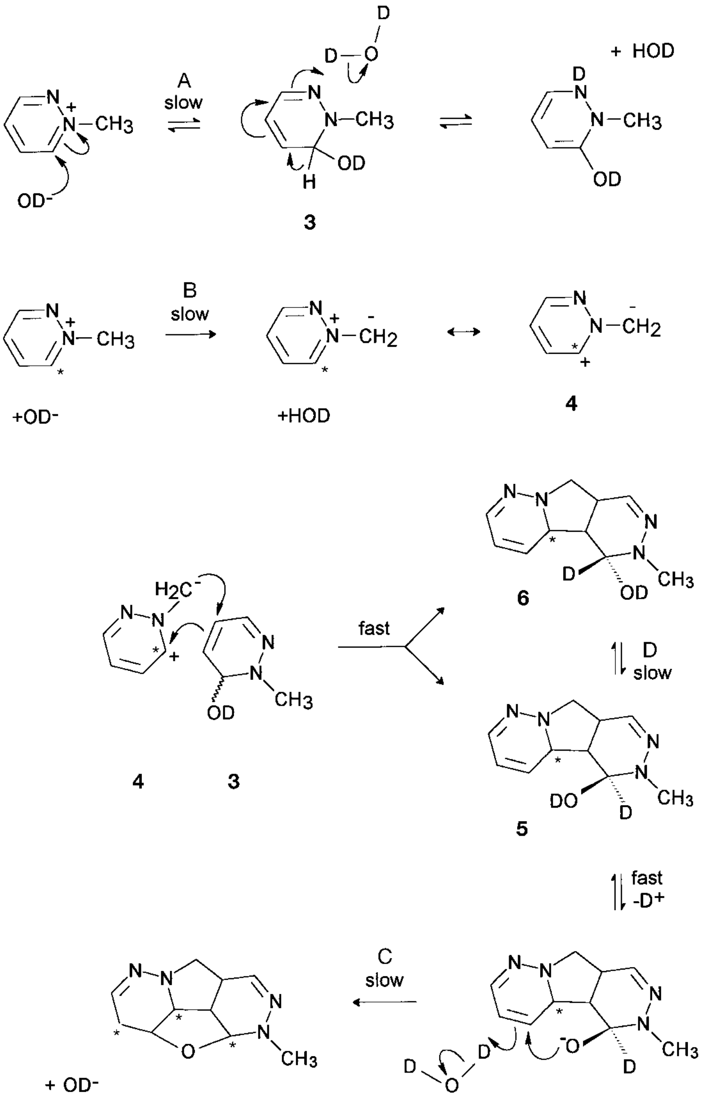


Figure 1. Molecular structure of **2** with atom-numbering scheme.

The available evidence is consistent with dimerization by the processes shown in Scheme 1. The first reaction visible by ^{1}H NMR spectroscopy for **1** in alkaline D_2O is H–D exchange at the *ortho* position (H-6, $\delta = 9.67$; equilibrium A in Scheme 1), which ultimately accounts for deuterium incorporation at C_{11} and C_{17} in **2** (numbering of atoms according to the crystal structure). Exchange appears to involve attack of OD^- at the *ortho* carbon atom (intermediate **3**), with subsequent hydrogen transfer facilitated by participation of the non-methylated nitrogen atom in a concerted process.

The second reaction is readily followed for pD > 11.5, where the remaining proton signals of **1** at $\delta = 9.48$ (1H, d), 8.56 (2H, m), and 4.66 (3H, s) decay in concert with simultaneous appearance of a plethora of new resonances. A major distinguishing feature of this process is the large primary kinetic isotope effect observed when the CH_3 group of **1** is replaced by CD_3. The observed rate constants at pD 12.30 are $k_{H(obs)} = (5.42 \pm 0.16) \times 10^{-4}\ s^{-1}$ and $k_{D(obs)} = (8.06 \pm 0.19) \times 10^{-5}\ s^{-1}$, respectively, hence $k_H/k_D = 6.7 \pm 0.6$. Thus, deprotonation of the methyl group of the reactant is rate determining for this step (step B in Scheme 1). Among the NMR signals that appear as a consequence of the second process are two N-Me singlets at $\delta = 2.77$ and 2.85, corresponding to diastereomers **5** and **6** ([**5**]:[**6**] = 1.5:1). Formation of these species occurs via intermediates **3** and **4** in a step that necessarily occurs faster than ylide reprotonation, since no deuterium incorporation is seen in either the methyl group or the C_{15} methylene group of the final product. The efficient scavenging of **4** by **3** is quite remarkable, since the latter never accumulates to a level that is detectable.



Scheme 1. Mechanism for the formation of **2** in D_2O. When not denoted explicitly as D, sites with incorporation of deuterium atoms are labeled with an asterisk.

Figure 2 shows changes in the intensities of the N-Me signals at pD = 12.65 as a consequence of the second, third, and fourth reactions. The third process reaches an advanced

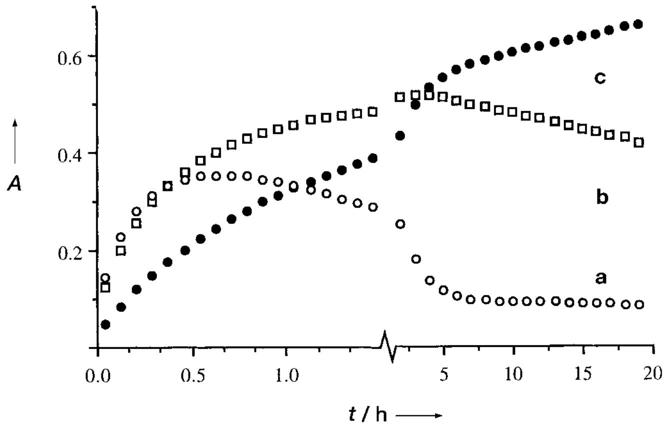


Figure 2. Changes in intensity (peak area A) as a function of time for the N-Me signals at $\delta = 2.77$ (a, ○), 2.85 (b, □), and 2.90 (c, ●) during dimerization of **1** in D_2O (ClO_4^- salt, 7.38 mg in 0.80 mL of 0.50 M phosphate buffer, pD = 12.65).

stage before the second is fully complete and is apparent through the growth of an additional N-Me resonance at $\delta = 2.90$. This increase occurs at the expense of the signal at $\delta = 2.77$ and corresponds to direct formation of **2** from deprotonated **5** (step C, Scheme 1). The reaction occurs with incorporation of deuterium at the adjacent carbon atom, which labels the C_{19} methylene group of **2**. The fourth process is a very slow conversion of **6** into **2**, as seen in the decay of the resonance at $\delta = 2.85$ as the signal at $\delta = 2.90$ increases in intensity (Figure 2). This reaction probably involves an inversion at carbon to give **5**, and cyclization as described above (step D, Scheme 1).

That **1** dimerizes so readily is certainly due to a fortuitous combination of steric and electronic factors not duplicated in other N-alkylated heterocycles.[5] The ability to add OH^- is clearly an important ingredient, since **3** emerges as a vital intermediate. Steric constraints may be responsible for a 10^2-fold reduction in dimerization rate when CH_3 in **1** is replaced by CH_3CH_2; however, the fact that electron donation deters ylide formation could also play a role. Whatever the exact nature of the influences, they lead to a new type of heterocycle in which a complex array of rings is assembled with a high degree of stereoselectivity.

Experimental Section

2: A solution of the I^- salt of **1** (170 mg) in H_2O (10 mL) was treated with NaOH (0.40 g, 10 mmol), and the solution was allowed to stand for 15 min. The aqueous phase was then saturated with NaCl and extracted with $CHCl_3$ (5 × 10 mL). The organic phase was decolorized with charcoal and evaporated, and the residue was crystallized from $CHCl_3$/pentane to yield 46 mg (58 %) of white crystals that slowly turn yellow on exposure to light. Elemental analysis calcd for $C_{10}H_{14}N_4O$: C 58.25, H 6.80, N 27.18; found: C 58.02, H 7.20, N 27.38; ^1H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 2.03$ (ddd, $^3J(H,H) = 16.5$, 3, 2 Hz, 1H, $H_{19}\beta$), 2.41 (brdd, $^3J(H,H) = 10$, 6 Hz, 1H, H_{17}), 2.43 (ddd, $^3J(H,H) = 16.5$, 5, 3 Hz, 1H, $H_{19}\alpha$), 2.98 (s, 3H, CH_3), 3.44 (ddd, $^3J(H,H) = 10$, 8, 7 Hz, 1H, H_{16}), 3.44 (dd, $^3J(H,H) = 12.5$, 6 Hz, 1H, $H_{15}\beta$), 3.86 (d, $^3J(H,H) = 12.5$ Hz, 1H, $H_{15}\alpha$), 4.00 (dd, $^3J(H,H) = 8$, 6 Hz, 1H, H_{14}), 4.11 (m, half-width = 14 Hz, 1H, H_{10}), 4.78 (d, $^3J(H,H) = 7$ Hz, 1H, H_{11}), 6.80 (dt, $^3J(H,H) = 5$, 2 Hz, $^4J(H,H) = 1.5$ Hz, 1H, H_{18}), 7.11 (s, 1H, H_{13}); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 23.8$ (C_{19}), 34.5 (C_{17}), 43.7 (CH_3), 48.7 (C_{16}), 62.2 (C_{15}), 66.4 (C_{14}), 68.3 (C_{10}), 87.8 (C_{11}), 136.2 (C_{18}), 148.3 (C_{13}).

NMR spectra (^1H, ^{13}C) were recorded at 25.0 ± 0.5 °C with a Varian VXRS-300 NMR spectrometer. Rate constants for reactions at constant pD were obtained from peak areas with least-squares fitting routines for simple first-order or consecutive first-order situations as appropriate. Values of the rate constants were independent of substrate concentration (3.5–15 mg in 0.80 mL of buffered D_2O solution). The pD values were determined with a Radiometer pHM 82 pH meter. Calibration for measurement in D_2O solution was accomplished by the method of Fife and Bruice;[6] pD = pH(measured) + 0.36 (25.0 °C).

Crystal data for colorless blocks grown from 1-butanol: crystal dimensions 0.70 × 0.60 × 0.20 mm; triclinic; space group $P1$; $a = 8.6390(10)$, $b = 10.490(2)$, $c = 12.391(2)$ Å, $\alpha = 99.080(10)$, $\beta = 96.500(10)$, $\gamma = 113.880(10)^\circ$, $V = 994.2(3)$ Å^3; $Z = 4$; $\rho_{calcd} = 1.378$ Mg m^{-3}; $T = 168(2)$ K; $2\theta_{max} = 45^\circ$, $Mo_{K\alpha}$ radiation ($\lambda = 0.71073$ Å); ω scans; 2513 measured reflections, 2513 independent reflections, 2513 refined reflections; absorption correction not applied; structure solution by direct methods (SHELXS-97);[7] refinement by full-matrix least squares on F^2 (SHELXL-97);[8] 245 parameters; 3 restraints; $wR2 = 0.2350$ for all data and a conventional $R1 = 0.0856$ for 2220 reflections with $I > 2\sigma I$; largest difference electron density peak and hole 0.502 and -0.444 e Å^{-3}. Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-100734. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: (+44) 1223-336-033; e-mail: deposit@ccdc.cam.ac.uk).

Received: October 7, 1997 [Z11011IE]
German version: *Angew. Chem.* **1998**, *110*, 1152–1154

Keywords: dimerizations · heterocycles · kinetics · NMR spectroscopy

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[1] The systematic name for **2** is 2-methyl-1a,2,4a,5,8,8a,8b,8c-octahydro-1-oxa-2,3,5a,6-tetraazacyclopent[1,2,3,4-*def*]fluorene.

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