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Photochemical behavior of 2,5-di-*tert*-butyl-3*H*-azepine: unexpected formation of a dicyclopenta[*b,e*]pyridine derivative and a *cis,cis*-cyclodeca-1,6-diene derivative

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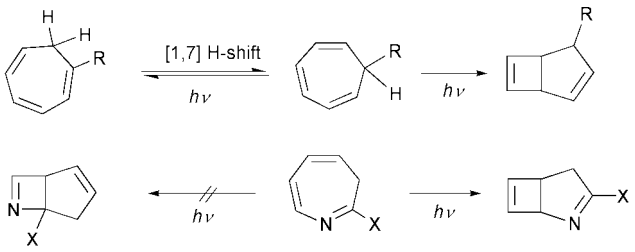
Hitherto unknown photochemical behavior of 3*H*-azepine giving cyclopent[*c*]azete and a (4π + 4π) photodimer is reported on the basis of an unexpected formation of a tricyclic dicyclopenta[*b,e*]pyridine derivative and a ten-membered-ring dicarbaldehyde by irradiation of 2,5-di-*tert*-butyl-3*H*-azepine in hexane.

Photochemistry of cycloheptatriene (CHT) derivatives has been extensively examined, whereas those of 3*H*-azepines have rarely been explored in spite of having a similar profile in both molecular and electronic structure to each other. Generally, irradiation of CHT derivatives has resulted in the formation of bicyclic compounds *via* intramolecular 4π photochemical electrocyclic reaction[1] and/or isomerized CHT *via* photochemically allowed [1,7] hydrogen shift.[2] Under gas-phase conditions, a ring contraction reaction leading to toluene derivatives was also observed.[3] A few photochemical researches have examined 3*H*-azepine with an electron donating group (–OR or $–NR_2$) at the 2 position. The reaction was rationalized by the formation of a cyclobuta[*b*]pyrrole derivative *via* ring closure between the 4 and 7 positions, exclusively.[4] Although 3*H*-azepine without any substituents has been found to be a labile substance[5] an electron donating group, imino ether or amidine conjugation, has been found to stabilize it.



We have reported the synthesis of dialkyl 3*H*-azepines, the stability of which was sufficient for treatment under atmospheric conditions when substituents were *tert*-butyl groups.[6] Since the stability of our 3*H*-azepines is not owing to conjugative stabilization, but steric protection by the bulky substituents, the behavior upon photoirradiation can be expected to be different from those reported. We wish to report the hitherto unknown photochemical behavior of 2,5-di-*tert*-butyl-3*H*-azepine **1**.

A solution of **1** (112 mg, 0.55 mmol) in hexane (100 ml) was irradiated using a high-pressure mercury lamp (100 W) with pyrex filter for 3 h at rt. Chromatography on silica gel of the resulting mixture gave 1,4a,7-tri-*tert*-butyl-3-pivaloyl-3,3a,4,4a,5,7a,8,8a-octahydrodicyclopenta[*b,e*]pyridin-8-ol **2** (63 mg, 61%) as colorless needles and 5,10-diamino-2,5,7,10-tetra-*tert*-butylcyclodeca-2,7-diene-1,6-dicarbaldehyde **3** (5 mg, 5%) as a yellow oil along with recovered 3*H*-azepine **1** (11 mg, 10%).[7] Fortunately, the structure of crystalline product **2** was determined by X-ray structural analysis (Fig. 1).[8] The obtained structure is considered to be an indirect product from the starting material because the molecule contains oxygen atoms which strongly suggests that it comes from a kind of dimer of **1**. The other product, **3**, showed a negative ion peak at *m*/*z* 445 (M − H, 7%) in the FAB MS spectrum. The mass number observed is compatible with two moles of **1** and two moles of water, therefore the precursor for **3** is also considered to arise from the dimer of **1**. The ^1H and ^{13}C NMR spectra of **3** suggest a symmetrical structure having formyl groups owing to δ_H 9.55 (d, J = 5.4 Hz) and δ_C 205.6 (d). The IR absorption bands at 3399 and 1707 cm^{-1} are attributable to amino and formyl groups, respectively. Therefore, the structure of **3** is considered to be a *cis,cis*-cyclodeca-1,6-diene skeleton formed from the hydrolysis of the imine moiety of the (4π + 4π) dimer **5**. According to the conformational analysis for *cis,cis*-cyclodeca-1,6-diene based on molecular mechanics, a chair form has been found to be the most stable form.[9] When the conformation of the ring maintains a chair form, the stereochemistry of **3** is determined to be as illustrated in Scheme 1 owing to both W-letter coupling, J = 2.1 Hz, between an *ipso*-proton of a formyl group and a methylene proton at δ_H 2.28 and molecular symmetry suggested by NMR spectra.

To obtain more detailed information about the reaction, we observed the *in situ* ^1H NMR spectrum during irradiation of **1** in cyclohexane-d_{12} under similar conditions. A gradual inverse relationship varying in time was observed between the peaks of 3*H*-azepine **1** and the peaks of **3** and a new compound **4**. No peaks corresponding to **2** were found during the irradiation. This means **3** formed quickly from (4π + 4π) photodimer **5** by hydrolysis with a trace of water in the solvent, but **2** formed

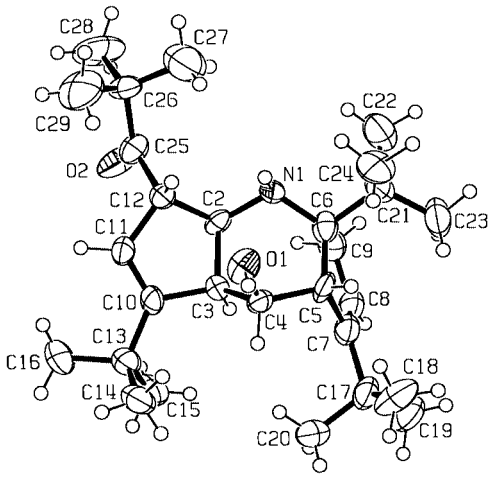


Fig. 1 Ortep drawing of structure **2**.

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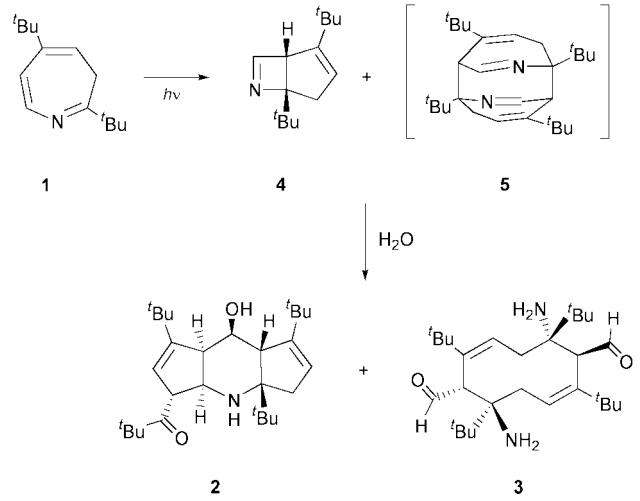
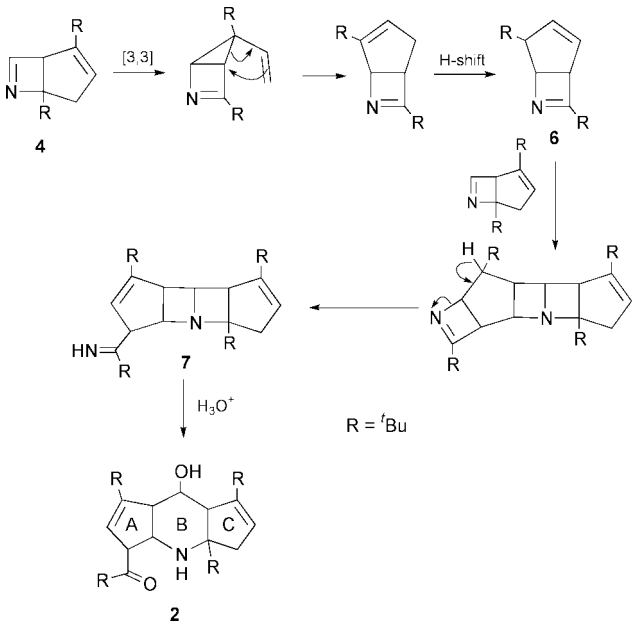


Scheme 1



Scheme 2

during chromatographic work from the initially formed photoproduct **4**. Attempts to isolate compound **4** were unsuccessful, however, GCMS showed *m*/*z* 205 (M^+, 0.4%) which is the same mass number as **1**. ^{1}H NMR data for **4** was obtained by the subtraction of known peak sets of **1**, **2** and **3** from the spectrum of a reaction mixture. The structure of **4** is estimated as 3,5a-di-*tert*-butyl-5,5a-dihydro-2a*H*-cyclopent[*c*]azete because of the doublet signal at δ_H 8.16 which is attributable to a –CH = N– moiety.

A possible route to **2** is illustrated in Scheme 2. The structure of the C-ring and a half of the B-ring of **2** are already in photoisomer **4** itself, but the pivaloyl group on the A-ring is not in the structure **4**. To access compound **2**, it is necessary to consider a formal ($2\pi + 2\pi$) addition between **4** and **6** which arises from **4** through the following sequence, [3,3] sigmatropic rearrangement, vinylcyclopropane rearrangement and finally 1,3-prototropy. Appropriate ring opening with participation of water on the adduct **7** leads to dicyclopenta[*b*,*e*]pyridine **2**.

We report here a new photochemical intramolecular ring closure at the 2 and 6 positions of 3*H*-azepine and ($4\pi + 4\pi$) photodimerization, although the yield of ($4\pi + 4\pi$) dimerization is relatively low compared to that of 4π electrocyclic reaction. An investigation is underway to clarify the photochemical behavior of 3*H*-azepine.

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Notes and references

1 For a review see O. L. Chapman, *Adv. Photochem.*, 1963, **1**, 323; G. W. Borden, O. L. Chapman, R. Swindell and T. Tezuka, *J. Am. Chem. Soc.*, 1967, **89**, 2979; W. G. Dauben and R. L. Cargill, *Tetrahedron.*, 1961, **12**, 186.

2 T. Tezuka, M. Kimura, A. Sato and T. Mukai, *Bull. Chem. Soc. Jpn.*, 1970, **43**, 1120; A. P. ter Boorg and H. Kloosterziel, *Rec. Trav. Chim.*, 1965, **84**, 241.

3 R. Srinivasan, *J. Am. Chem. Soc.*, 1962, **84**, 3432.

4 R. A. Odum and B. Schmall, *J. Chem. Soc., Chem. Commun.*, 1969, 1209.

5 E. Vogel, H.-J. Altenbach, J.-M. Drossard, H. Schmickler and H. Stegelmeier, *Angew. Chem., Int. Ed. Engl.*, 1980, **19**, 1016.

6 K. Satake, R. Okuda, M. Hashimoto, Y. Fujiwara, H. Okamoto, M. Kimura and S. Morosawa, *J. Chem. Soc., Perkin Trans. 1*, 1994, 1753.

7 Physical data for **2**: colorless needles, mp 178–179 °C; ^{1}H NMR (270 MHz, $CDCl_3$) δ 5.49 (br s, 1H), 5.31 (br s, 1H), 4.34 (br s, 1H), 4.04 (dd, J = 6.8 and 5.4 Hz, 1H), 3.9 (m, 1H), 3.5 (br, 1H), 3.07 (br s, 1H), 2.90 (br d, J = 6.8 Hz, 1H), 2.65 (br d, J = 17.6 Hz, 1H), 2.5 (br, 1H), 2.21 (dd, J = 17.6 and 2.4 Hz, 1H), 1.18 (s, 9H), 1.14 (s, 9H), 1.12 (s, 9H), 0.89 (s, 9H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 217.9 (s), 155.1 (s), 151.5 (s), 126.1 (d), 122.4 (d), 70.0 (d), 68.3 (s), 61.0 (d), 57.6 (d), 52.7 (d), 45.3 (d), 44.5 (t), 37.4 (s), 34.6 (s, 2C), 33.3 (s), 31.1 (q), 30.2 (q), 25.8 (q), 24.5 (q); IR (KBr) 3476, 2960, 2872, 1694 cm^{-1}; MS (FAB) *m*/*z* 430 (M^+, 100%), 372 (48), 57 (19); UV-Vis λ_{max} (EtOH) 204 (log ε 3.87) nm; HRMS (FAB) calcd for $C_{28}H_{48}NO_2$ 430.3685, found 430.3654; anal. calcd for $C_{28}H_{47}NO_2$: C, 78.27; H, 11.03; N, 3.26. Found: C, 78.16; H, 11.00; N, 3.24%. Physical data for **3**: yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.55 (d, J = 5.4 Hz, 2H), 5.68 (ddd, J = 2.8 and 2.7 and 0.9 Hz, 2H), 3.35 (ddd, J = 5.4 and 2.1 and 0.9 Hz, 2H), 2.72 (dd, J = 17.1 and 2.7 Hz, 2H), 2.28 (ddd, J = 17.1 and 2.8 and 2.1 Hz, 2H), 1.50 (br, 4H), 1.03 (s, 18H), 0.88 (s, 18H); ^{13}C NMR (67 MHz, $CDCl_3$) δ 205.6 (d), 150.0 (s), 126.5 (d), 70.1 (s), 63.1 (d), 43.9 (t), 38.7 (s), 33.5 (s), 29.7 (q), 24.3 (q); IR (neat) 3399, 2966, 2872, 1707, 1436, 1365 cm^{-1}; UV-Vis λ_{max} (hexane) 246 sh (log ε 3.35), 293 (3.37) nm; HRMS (FAB) calcd for $C_{28}H_{49}N_2O_2$ 445.3794, found 445.3768. ^{1}H NMR data for **4** (300 MHz, cyclohexane-d_{12}): δ 8.16 (br d, 1H), 5.35 (t, J = 2.4 Hz, 1H), 3.64 (dd, J = 3.6 and 1.5 Hz, 1H), 2.53 (dd, J = 18 and 2.4 Hz, 1H), 2.22 (ddd, J = 18 and 2.4 and 1.5 Hz, 1H), 1.05 (s, 9H), 0.92 (s, 9H).

8 Crystal data for **2**: $C_{28}H_{47}NO_2$, M = 429.68, orthorhombic, a = 11.400(2), b = 21.835(6), c = 10.935(5) Å, V = 2721.9(12) Å^3, T = 298 K, space group $P2_12_12_1$, Z = 4, μ(Mo-K$_\alpha$) = 0.060 mm^{-1}, 2693 unique ($2\theta_{max}$ = 50°, R_{int} = 0.050) reflections were used in refinement. The final $wR(F)$ was 0.178 for the unique reflections and $R(F)$ was 0.089 for 1468 reflections larger than $2\sigma(I)$. The reflections in the high 2θ range were weak probably because of the large thermal displacements of the four *tert*-butyl groups in the molecule. Relatively large final $wR(F)$ and $R(F)$ may be caused by this fact. The absolute configuration has not been determined. CCDC 158826. See http://www.rsc.org/suppdata/cc/b1/b101225h/ for crystallographic data in .cif or other electronic format.

9 N. L. Allinger, M. T. Tribble and J. T. Spraguue, *J. Org. Chem.*, 1972, **37**, 2423.