227. Light-induced Dehydrodimerization of 3-Hydroxypyrroles

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Summary

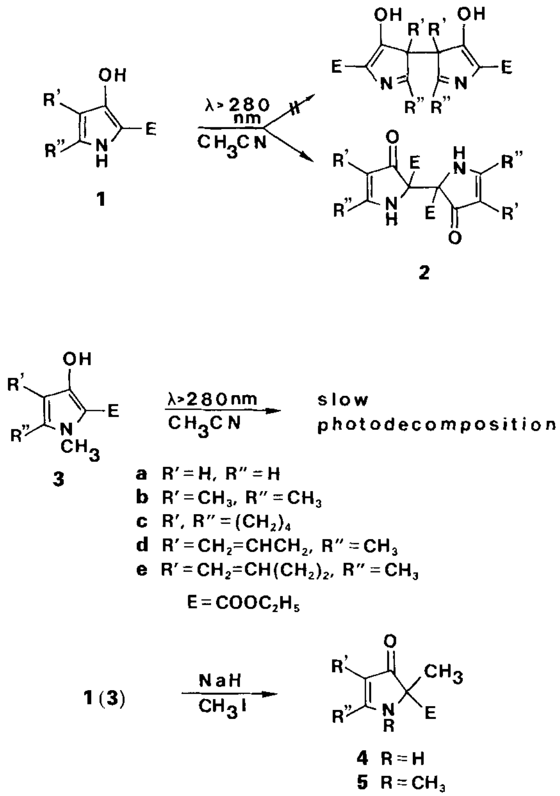
Irradiation ($\lambda > 280$ nm) of 3-hydroxy-1*H*-pyrrole-2-carboxylates **1** in CH_3CN gives the [2,2′-bi(3-oxo-2,3-dihydro-1*H*-pyrrole)]-2-,2′-dicarboxylates **2** in reasonable to good yields. The corresponding *N*-methylpyrroles **3** only undergo slow photodecomposition under similar conditions. Several 2-methyl-3-oxo-2,3-dihydro-1*H*-pyrrole-2-carboxylates **4** and **5** were synthesized to compare their spectral data with those of the dehydrodimers **2**. A X-ray structure analysis was performed for diethyl [2,2′-bi(4,5-dimethyl-3-oxo-2,3-dihydro-1*H*-pyrrole)]-2,2′-dicarboxylate (**2b**). The originally proposed [3,3′-bi(3*H*-pyrrole)] structure for compounds **2a–e** proves incorrect.

We have recently reported preliminary results on the first example of a light-induced dehydrodimerization of pyrroles [1]. From the UV, IR and ^{1}H-NMR spectra, we had concluded that the dehydrodimers were [3,3′-bi(3*H*-pyrroles)]. We have now established that the originally proposed constitution for the dehydrodimers of **1** was wrong and that photoproducts **2** are indeed [2,2′-bi(1*H*-pyrroles)] by a X-ray structure analysis of **2b** and the ^{13}C-NMR spectra of **2** (this data was not available at the time of the preliminary communication). We have also investigated the photochemical behaviour of the *N*-methylpyrroles **3**, and finally, we have synthesized several 2-methyl-3-oxo-1*H*-2,3-dihydro-pyrrole-2-carboxylates **4** and **5** *via* alkylation of **1** and **3**, respectively, to compare their spectra with those of **2** *(Scheme 1)*.

Irradiation of Hydroxypyrroles 1 and 3. – As described [1], irradiation ($\lambda > 280$ nm) of 10^{-2}M solutions of **1** in thoroughly degassed CH_3CN gives dehydrodimers **2**, the formation of which was explained as occuring *via* electron transfer from excited **1** to the solvent. Under similar experimental conditions no photoproducts could be isolated from the *N*-methylpyrroles **3**, although the disappearance of starting material (as monitored by UV spectroscopy) is not much slower than for compounds **1**.

Alkylation of 1 and 3. – Treatment of thoroughly degassed solutions of **1** (**3**) with NaH and CH_3I afforded compounds **4** and **5**, respectively, with the exception of **1b**, where further methylation of **4b** to **5b** is apparently faster than its formation, thus only allowing the isolation of **5b** even when working with less than equimolar amounts of

Scheme 1



1 **2** **3**

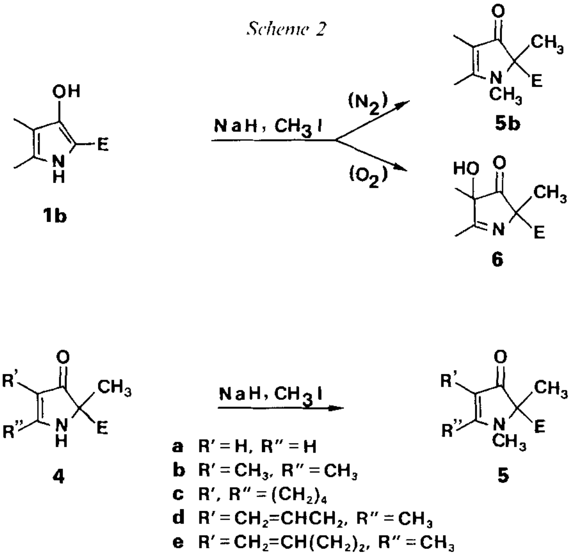
a R' = H, R" = H
b R' = CH_3, R" = CH_3
c R', R" = $(CH_2)_4$
d R' = CH_2=$CHCH_2$, R" = CH_3
e R' = CH_2=$CH(CH_2)_2$, R" = CH_3

E = $COOC_2H_5$

1 (**3**)

4 R = H
5 R = CH_3

Scheme 2



1b **5b** **6**

4 **5**

a R' = H, R" = H
b R' = CH_3, R" = CH_3
c R', R" = $(CH_2)_4$
d R' = CH_2=$CHCH_2$, R" = CH_3
e R' = CH_2=$CH(CH_2)_2$, R" = CH_3

Table 1. *Spectroscopic Data of* **2**, **4**, **5** *and* **6**

Compound[a]	UV (CH_3CN)	IR (CCl_4)	^{1}H-NMR ($CDCl_3$)	^{13}C-NMR ($CDCl_3$)	MS
2a	305 (4.02)	1740, 1680[b]	[c]	191 (*s*); 168 (*s*); 166 (*d*); 99 (*d*); 73 (*s*); 63 (*t*); 14 (*q*).	[c]
2b	309 (4.08)	1740, 1690	4.20 (*q*, 4H); 2.19 (*s*, 6H); 1.49 (*s*, 6H); 1.21 (*t*, 6H).	191 (*s*); 175 (*s*); 169 (*s*); 106 (*s*); 74 (*s*); 63 (*t*); 15, 14, 6 (*q*).	[c]
2c	309 (4.00)	1740, 1690	[c]	190 (*s*); 178 (*s*); 169 (*s*); 108 (*s*); 74 (*s*); 63, 26, 23, 22, 19 (*t*); 14 (*q*).	[c]
2d	311 (3.95)	1740, 1690	[c]	190 (*s*); 177 (*s*); 168 (*s*); 135 (*d*); 114 (*t*); 108 (*s*); 73 (*s*); 63, 25 (*t*); 15, 14 (*q*).	[c]
2e	309 (4.04)	1740, 1690	[c]	–	[c]
4a	308 (4.03)	1740, 1680	8.05 and 5.18 (*AB*, *J* = 3.5); 4.23 (*q*, 2H); 1.56 (*s*, 3H); 1.27 (*t*, 3H).	187 (*s*); 168 (*s*); 156 (*d*); 99 (*d*); 69 (*s*); 62 (*t*); 21, 14 (*q*).	169 (M^+) *110*
4c	315 (4.09)	1730, 1640	4.21 (*q*, 2H); 2.43 (*m*, 2H); 2.16 (*m*, 2H); 1.71 (*m*, 4H); 1.54 (*s*, 3H); 1.26 (*t*, 3H).	196 (*s*); 177 (*s*); 169 (*s*); 108 (*s*); 70 (*s*); 62 (*t*); 30–18 (*m*); 14 (*q*).	223 (M^+) *150*
4d	316 (4.07)	1730, 1680	5.79 (*m*, 1H); 4.98 (*m*, 2H); 4.23 (*q*, 2H); 2.92 (*d*, 2H); 2.15 (*s*, 3H); 1.56 (*s*, 3H); 1.26 (*t*, 3H).	–	223 (M^+) *138*
4e	317 (4.06)	1730, 1690	5.77 (*m*, 1H); 4.95 (*m*, 2H); 4.23 (*q*, 2H); 2.20 (*m*, 4H); 2.15 (*s*, 3H); 1.52 (*s*, 3H); 1.26 (*t*, 3H).	–	237 (M^+) *152*
5a	326 (3.95)	1730, 1670	7.82 and 5.06 (*AB*, *J* = 3.5); 4.23 (*q*, 2H); 3.08 (*s*, 3H); 1.56 (*s*, 3H); 1.26 (*t*, 3H).	198 (*s*); 167 (*d*); 166 (*s*); 95 (*d*); 73 (*s*); 62 (*t*); 34, 18, 14 (*q*).	183 (M^+) *110*
5b	334 (4.05)	1730, 1670	4.20 (*q*, 2H); 2.99 (*s*, 3H); 2.17 (*s*, 3H); 1.69 (*s*, 3H); 1.53 (*s*, 3H); 1.26 (*t*, 3H).	195 (*s*); 173 (*s*); 167 (*s*); 103 (*s*); 74 (*s*); 62 (*t*); 30, 18, 14, 13, 7 (*q*).	211 (M^+) *138*
5c	332 (4.03)	1730, 1660	4.23 (*q*, 2H); 2.95 (*s*, 3H); 2.49–2.23 (*m*, 4H); 1.75 (*m*, 4H); 1.56 (*s*, 3H); 1.27 (*t*, 3H).	–	237 (M^+) *164*
5d	331 (4.03)	1730, 1670	5.77 (*m*, 1H); 4.94 (*m*, 2H); 4.18 (*q*, 2H); 2.95 (*s*, 3H); 2.89 (*m*, 2H); 2.11 (*s*, 3H); 1.50 (*s*, 3H); 1.21 (*t*, 3H).	–	237 (M^+) *164*
5e	333 (4.04)	1730, 1670	5.77 (*m*, 1H); 4.97 (*m*, 2H); 4.17 (*q*, 2H); 2.95 (*s*, 3H); 2.20 (*m*, 4H); 2.12 (*s*, 3H); 1.47 (*s*, 3H); 1.21 (*t*, 3H).	–	251 (M^+) *210*
6	328 (1.98)	1760, 1720[b], 1640	4.20 (*q*, 2H); 2.22 (*s*, 3H); 1.55 (*s*, 3H); 1.44 (*s*, 3H); 1.25 (*t*, 3H).	214 (*s*); 181 (*s*); 168 (*s*); 78 (*s*); 77 (*s*); 62 (*t*); 22, 21, 16, 14 (*q*).	213 (M^+) *112*

[a] All new compounds gave satisfactory elemental analyses.

[b] In KBr.

[c] *Cf.* [1].

CH_3I. Compounds **5d** and **5e** were obtained by alkylation of **4d** and **4e**, respectively, as the corresponding *N*-methyl-hydroxypyrroles **3d** and **3e** were not available. In the presence of traces of O_2, the only product formed by alkylation from **1b** is ethyl 3-hydroxy-5-methyl-4-oxo-4,5-dihydro-3*H*-pyrrole-5-carboxylate **6** *(Scheme 2)*. The spectral data of compounds **2**, **4**, **5** and **6** are summarized in *Table 1*.

Table 2. *Atom Coordinates* (× 10^4) *and Equivalent Isotropic Temperature Factors* B_{eq} (Å^2) *of* **2b**

Atom	x	y	z	B_{eq}[a])
N(1)	4256(4)	2021(5)	8766(5)	3.6(3)
C(2)	4091(6)	1588(5)	9667(5)	3.9(3)
C(21)	5068(8)	1567(7)	10374(7)	5.2(4)
C(3)	2966(6)	1202(5)	9791(6)	4.2(3)
C(31)	2501(10)	638(9)	10676(8)	6.2(5)
C(4)	2301(6)	1476(5)	8954(5)	3.8(3)
O(4)	1241(4)	1393(4)	8786(4)	4.5(2)
C(5)	3170(5)	2008(5)	8191(5)	3.4(3)
C(6)	2721(6)	3136(5)	7962(7)	4.3(3)
O(6)	2254(5)	3379(4)	7198(5)	5.8(3)
O(7)	2838(5)	3746(4)	8766(5)	6.2(3)
C(7)	2409(10)	4798(7)	8661(11)	8.3(7)
C(8)	3291(12)	5601(8)	8744(20)	11.1(10)
N(1′)	2160(5)	1187(4)	6747(5)	4.0(3)
C(2′)	1838(6)	144(5)	6824(6)	4.4(3)
C(21′)	643(8)	− 180(8)	6516(9)	6.3(5)
C(3′)	2691(6)	− 463(5)	7210(6)	4.3(3)
C(31′)	2704(9)	− 1653(6)	7353(8)	6.2(5)
C(4′)	3691(6)	177(5)	7465(5)	4.2(3)
O(4′)	4663(3)	− 69(4)	7773(4)	4.8(2)
C(5′)	3295(5)	1347(5)	7233(5)	3.6(3)
C(6′)	4194(6)	1850(5)	6537(5)	4.2(3)
O(6′)	4777(4)	2605(4)	6740(4)	4.8(2)
O(7′)	4270(5)	1293(5)	5696(4)	6.3(3)
C(7′)	5182(10)	1662(8)	4956(7)	7.4(6)
C(8′)	4562(12)	2418(10)	4317(10)	9.9(8)

[a]) B_{eq} is in the form $4(b_{11}/a^{*2}b_{22}/b^{*2}b_{33}/c^{*2})^{1/3}$.

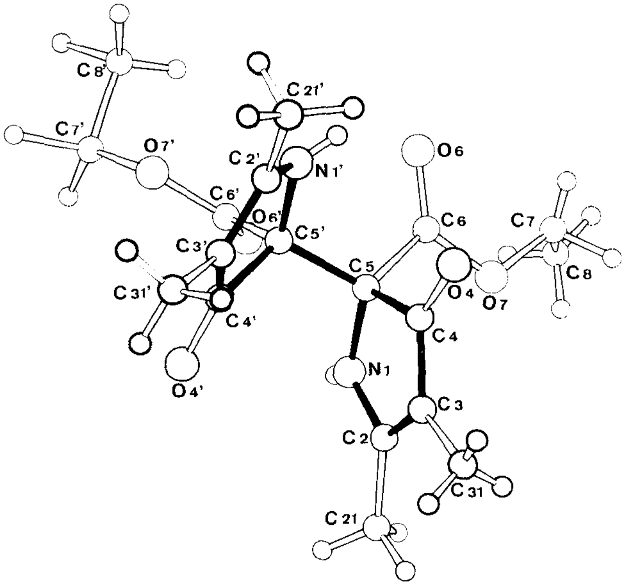


Figure. *ORTEP drawing and atom numbering scheme of* **2b**

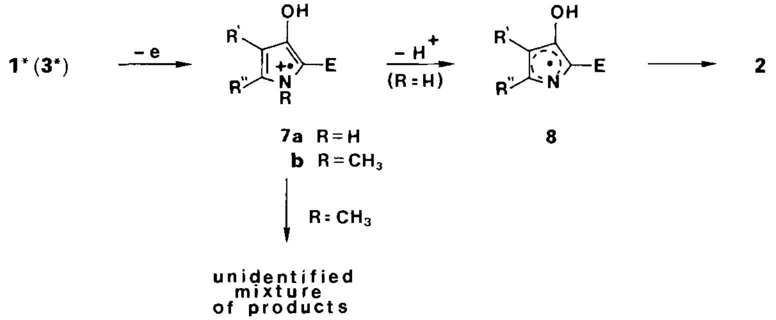
X-Ray Structure Analysis of 2b. – a) *Crystal Data.* Dehydrodimer **2b** crystallizes in the orthorhombic space group *Pna*2_1 with four formula units $C_{18}H_{24}N_2O_6$ in the unit cell: $a = 11.353(1)$, $b = 12.603(1)$, $c = 13.422(1)$ Å; $\alpha = \beta = \gamma = 90°$; $D_x = 1.260$ mg·m^{-3}; $M_r = 364.4$; $\mu(\mathrm{Cu}K_\alpha) = 0.71$ mm^{-1}. Cell parameters were obtained by least-squares refinement from the angular settings of 21 reflections in the interval $19 < \theta < 29°$. b) *Data Collection.* Crystal size: 0.08 × 0.09 × 0.34 mm^3; temp. 293°K; $\sin\theta_\lambda = 0.588$ Å^{-1}, $\theta - 2\theta$ scan technique, zig-zag mode. Intensities collected: 2661; reflections observed: 1287; reflections unobserved: 205; rejection criterion: $I < 36(I)$.

c) *Structure Determination and Refinement.* The structure was solved by direct methods with *MULTAN* [2]. The full matrix least-squares refinement was done with *SHELX* [3]. H-Atom positions were calculated with *XANADU* [4] and refined with fixed isotropic temperature factors at $U = 0.04$ Å^2. One half of the molecule was blocked alternatively and 154 parameters were varied in every cycle. The final R is 0.058 for 1287 observed reflections, based on unit weights. Max. and min. heights in final difference *Fourier* synthesis were 0.20 and − 0.24 e Å^{-3}, atomic scattering factors from *SHELX*. Final atomic coordinates and equivalent isotropic temperature factors (B_{eq}) are given in *Table 2*. The atom numbering scheme of the structure of **2b** is shown in the *ORTEP* [5] drawing in the *Figure*[1]).

Discussion. From the few results reported in the literature it would seem that oxidative coupling of pyrroles with $Pb(OAc)_4$, $K_3Fe(CN)_6$ or $FeCl_3$ usually affords [2,2′-bi(1*H*pyrroles)] when the heterocycle is unsubstituted on either C(2) or C(5) [6–8]. The one 2,3,4,5-tetrasubstituted pyrrole investigated – 3-acetyl-2-methyl-4,5-diphenylpyrrole [9] – affords a mixture of two dehydrodimers.

In our first analysis of the dehydrodimers of **1**, the constitution of the products resulted from the mass spectra, elemental analyses and the ^{1}H-NMR spectra. Without any comparative means available, the UV- and IR spectra were not too helpful to discern between a [2,2′-bi(1*H*-pyrrole)] and a [3,3′-by(3*H*-pyrrole)] structure. This latter one seemed to be more reasonable on the basis of the ^{1}H-NMR spectrum of **2b**, wherein the chemical shift of one of the CH_3-groups at $\delta = 1.49$ ppm (in $CDCl_3$) indicated that this CH_3-group was bound to an sp^3-hybridized C-atom. On the other hand, we were puzzled by the fact that the photoproduct of **1a** although exhibiting the same spectral characteristics as the other photoproducts, would not tautomerize to a [3,3′-bi(1*H*-pyrrole)] [1]. The X-ray structure analysis of **2b** as well as the now available comparative spectral data of compounds **4** and **5**, specially the ^{13}C-NMR spectra of **2a**, **4a** and **5a** clearly establish that our original assignment of the constitution of photoproducts **2** was wrong.

Scheme 3



The result that the *N*-methylpyrroles **3** do not undergo an analogous oxidative coupling reaction as **1** provides additional information regarding the mechanism of this reaction. It can thus be assumed that the cation radical **7a** formed *via* electron transfer

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[1]) Additional material can be ordered referring to the n° CSD 50957, names of the authors and citation of the paper at the *Fachinformationszentrum Energie–Physik–Mathematik*, D–7514 Eggerstein-Leopoldshafen 2, FRG.

from excited **1** to the solvent deprotonates to the radical **8**, and that the dehydrodimers **2** are formed by dimerisation of this species. The cation radical with R = CH_3 (**7b**) cannot undergo this step and is therefore converted to other non-identified products *(Scheme 3)*.

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Experimental Part

General. Absorptions in the UV spectra are given in nm (log ε) and in the IR spectra in cm^{-1}. Chemical shifts in the 400-MHz ^1H- and 100.63-MHz ^{13}C-NMR spectra are given in ppm relative to TMS (= 0 ppm) as internal standard. The mass spectra were measured at 70 eV. The X-ray data were collected on an *Enraf-Nonius CAD-4* diffractometer fitted with a graphite monochromator.

Starting Materials. Pyrroles **1a** [10], **1b** [11], **1c** [11], **1d** [1], **1e** [1], **3a** [10], **3b** [12] and **3c** [13] were synthesized according to the references indicated.

A solution of 10^{-3} mol **1** in 100 ml CH_3CN was thoroughly degassed with Ar and then irradiated through *Pyrex* for 48 h with a 250 W Hg lamp. The degree of conversion was > 80% (TLC). Evaporation of the solvent, chromatography (SiO_2, CH_2Cl_2/CH_3OH 95:5) and recrystallization from cyclohexane afforded **2** as a mixture of diastereoisomers (for yields and m.p., *cf.* [1]).

Photolysis of **3**. Irradiation of the *N*-methylpyrroles **3** under the same conditions as above led to decomposition of starting material without formation of a (or several) main product(s) as monitored by TLC.

Preparation of **4** *and* **5** (*from* **1** *and* **3**, *respectively*). A solution of 3 mmol **1** (**3**) in 10 ml dry benzene was added to a stirred suspension of 3 mmol NaH in 20 ml benzene under N_2. After warming at 60° for 1 h, a solution of 9 mmol CH_3I in 20 ml benzene was added dropwise; the mixture was then refluxed for 4 h, cooled and filtered. Evaporation of the solvent and chromatography (SiO_2,AcOEt/hexane 2:1) afforded: **4a** (m.p. 98°, 70%), **4c** (m.p. 48°, 75%), **4d** (m.p. 64°, 85%), **4e** (m.p. 105°, 70%), **5a** (oil, 88%), **5b** (oil, 65%), **5c** (oil, 80%).

Preparation of **5b** (*from* **1b**). The same procedure as above using 3 mmol **1b**, 9 mmol NaH and 30 mmol CH_3J afforded **5b**, m.p. 128° in 35% yield.

Preparation of **5d** *and* **5e** (*from* **4d** *and* **4e**, *respectively*). The same procedure as above using 3 mmol **4d** (resp. **4e**), 9 mmol NaH and 30 mmol CH_3I afforded **5d** (oil, 70%) and **5e** (oil, 53%).

Preparation of **6**. A solution of 3 mmol **1b** in 10 ml benzene was added to a stirred non-degassed suspension of 3 mmol NaH in 20 ml benzene. After warming at 60° for 1 h, a solution of 9 mmol CH_3I in 20 ml benzene was added dropwise; the mixture was then refluxed for 4 h, cooled and filtered. Workup as above yielded **6** (m.p. 163°, 60%).

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