73. Photochemical Rearrangements of 5,6-Epimino-5,6-dihydro-β-ionone and Derivatives

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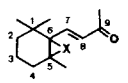
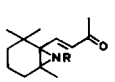
On irradiation at −20°, 5,6-epimino-5,6-dihydro-β-ionone (*E*)-**3** rearranges to the products **6** and **7**. The *N*-methyl derivative (*E*)-**4** does not lead to any photoproduct upon brief irradiation; on prolonged irradiation, only unspecific photodecomposition is observed. The *N*-acylated derivative (*E*)-**5** undergoes rapid (*E*)/(*Z*)-isomerization and slow rearrangement to **12** and **13**.

1. Introduction. – In recent years, the photochemistry of conjugated epoxyenones in the ionone series, *e.g.* **1**, has been investigated systematically. From these studies, it has become clear that intrinsically the mode of excitation is decisive of the photoprocesses. Thus, on $^1n,\pi^*$-excitation, (*E*)/(*Z*)-isomerization and/or product formation *via* [C(6)–O]-bond cleavage[1]) is observed, whereas $^1\pi,\pi^*$-excitation also causes formation of carbonyl ylides and carbene intermediates [2]. The photochemistry of the methano-analogous compound **2** was also studied and, in general, gave the same results [3].



1 X = O
2 X = CH_2



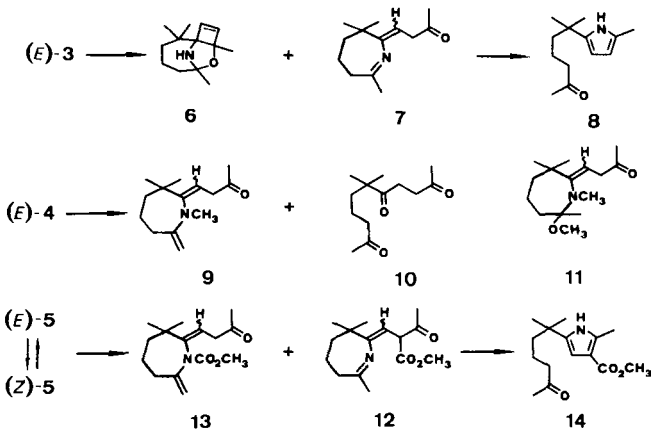
(*E*)-**3** R = H
(*E*)-**4** R = CH_3
(*E*)-**5** R = CO_2CH_3

The recently performed synthesis of 5,6-epimino-5,6-dihydro-β-ionone ((*E*)-**3**) and its *N*-substituted derivatives (*E*)-**4** and (*E*)-**5** [4] [5] rendered it possible to extend these photochemical investigations to the N-analogous compounds. Herein, it was of particular interest to compare the results with those obtained from photolysis of **1** and **2**, especially as the *thermal* behaviour of (*E*)-**3**, (*E*)-**4**, and (*E*)-**5** [5] is the same as that of the O- and C-analogues [3] [6].

2. Photolyses. – 2.1. *Photolysis of* (E)-**3**. Irradiation (λ = 254 nm, > 280 nm, ≧ 347 nm) of (*E*)-**3** in CD_3CN or C_6D_{12} at r.t. led to mixtures of the products **6** and **7** (*Scheme 1*). As shown later (see *Chap. 3*), these compounds are very unstable in solution: thus, **6** rearranged easily by thermal reaction to **7**, which in turn was further converted into the pyrrole derivative **8** [5]. Therefore, to avoid secondary thermal processes, irradiations were performed in dry CD_3CN at −20°. At this temperature, **6** did not convert thermally into **7** to a detectable extent during the time necessary for photolysis.

[1]) In ionone derivatives, numbering according to the carotenoid nomenclature is used [1].

Scheme 1



At −20°, irradiation (λ = 254 nm, conversion > 95%) caused formation of a two-component mixture consisting of *ca.* 15% **6** and 85% **7** (estimated by ^{1}H-NMR), while at $\lambda > 280$ nm and $\geqq 347$ nm (conversion > 90%), the ratio **6**/**7** changed to *ca.* 2:1. Whereas isolation of **7** was not possible (*cf.* [5]), isolation of the tricyclic photoisomer **6** was easily performed due to its low solubility and high crystallisation tendency: by irradiation ($\lambda > 280$ nm) of a *ca.* 1.3M solution of (*E*)-**3** in CH_3CN and subsequent filtration, **6** could be isolated in 68% yield.

2.2. *Photolysis of* (E)-**4.** The *N*-methylated derivative (*E*)-**4** showed a different behaviour. On irradiation (λ = 254 nm, > 280 nm, $\geqq$ 347 nm) in CD_3CN at r.t. and at −30°, (*E*)-**4** underwent slow photodecomposition affording deep red solutions. By ^{1}H-NMR, **9** and **10** were the only detectable products; after flash chromatography, the triketone **10** was the only one isolated in low yield.

As the appearance of a blue colour on irradiation of a frozen CD_3CN solution of (*E*)-**4** strongly indicates the formation of azomethine ylides (*cf.* [7]), attempts were made to trap an intermediary ylide by irradiation in the presence of dimethyl maleate (DMM). The results were substantially the same as in absence of DMM. According to ^{1}H-NMR, the formation of cycloaddition products can be excluded. Also by irradiation in CH_3OH, no further proof of an intermediary ylide was obtained, as the expected product **11** could neither be isolated nor detected by ^{1}H-NMR in the photolysis solution.

2.3. *Photolysis of* (E)-**5.** Brief irradiation (λ = 254 nm, > 280 nm, $\geqq$ 347 nm) of (*E*)-**5** in CD_3CN produced a 4:1 mixture of (*E*)- and (*Z*)-**5.** On prolonged irradiation ($\lambda \geqq 347$ nm, conversion > 85%), the following product distribution was estimated by ^{1}H-NMR[2]): (*Z*)-**5** (< 5%), **12** (*ca.* 60%), **13** (*ca.* 10%), and unknown products (*ca.* 25%). Irradiation at $\lambda > 280$ nm caused (*E*)/(*Z*)-isomerization and formation of **12** and **13** in the same ratio as above; during the irradiation, the amount of **12** decreased, presumably due to secondary photoprocesses. For the same reason, irradiation at λ = 254 nm also gave no clear result, apart from (*E*)/(*Z*)-isomerization.

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[2]) A more accurate determination was not possible since **12** is very sensitive to moisture and, therefore, could not be isolated without transformation (see *Chap. 3*).

2.4. *Photolysis of (Z)*-**5**. Irradiation of (*Z*)-**5** in CD_3CN ($\lambda \geqq 347$ nm) rapidly caused (*E*)/(*Z*)-isomerization, and the photolysis proceeded to the same product distribution as that resulting from irradiation of the (*E*)-isomer.

3. Structure of the Compounds. – Products **7, 9,** and **13** have also been obtained by thermolysis and, therefore, are described in a previous paper dealing with this subject [5]; **10** was identified by comparison of its analytical data with those published by other authors [8]. The structures of the new compounds were deduced from the spectral data, of

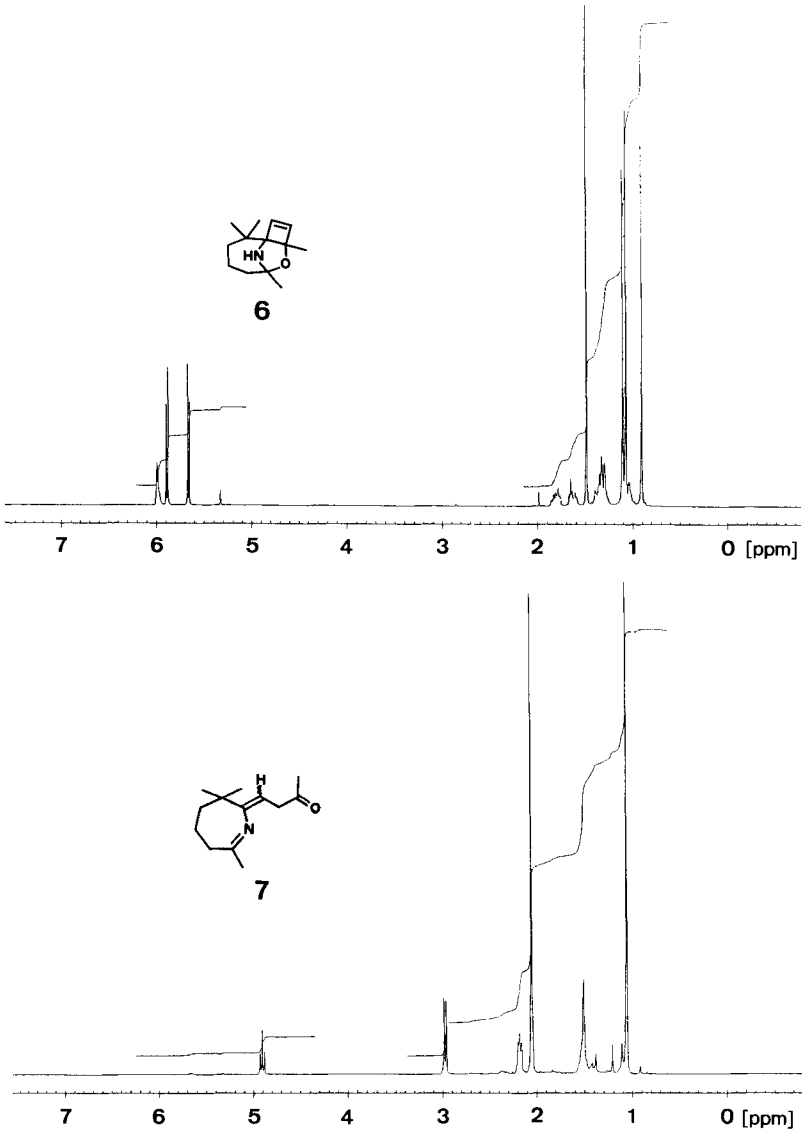
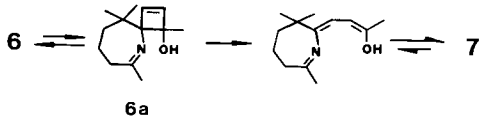


Fig. *^{1}H-NMR spectra* (300 MHz, CD_2Cl_2) *of* **6** (at 237K) *and* **7** *obtained on standing of the sample of* **6** *at 0° for 5 days*

Scheme 2



6a

which only the most relevant are discussed herein (full data, see *Exper. Part*), and further confirmed by chemical transformations.

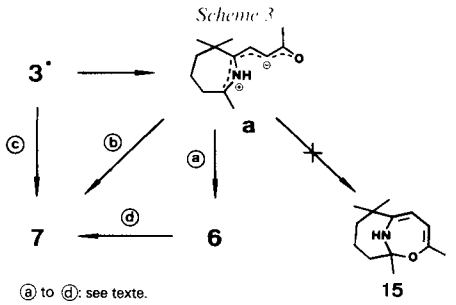
Tricyclic Oxazolidine **6.** The MS shows a molecular peak at *m/z* 207 indicating the molecular formula $C_{13}H_{21}NO$ which is also evidenced by the elemental analysis. In the IR, the lack of any strong absorption between 1750 and 1600 cm^{-1} is most indicative as well as the broad absorption in the 3200 cm^{-1} region and the triple band at 1160, 1130, and 1090 cm^{-1} which are characteristic for oxazolidines [9]. In the ^{1}H-NMR, 2*d* (J = 5.4) of 2 olefinic H-atoms should be mentioned, which together with 2*d* at 131.29 and 135.75 ppm and 3*s* at 53.19, 67.98, and 97.93 ppm in the ^{13}C-NMR prove the fused 4/5-ring system. The structure of the remaining part of the molecule is evidenced by the conversion of **6** into the known **7** [5] which proceeds easily and uniformly upon standing of the NMR solution at 0° (see *Scheme 2* and *Fig.*). This remarkable reaction is easily rationalized by the well established equilibrium between oxazolidines and the corresponding *Schiff* bases [9]: indeed, in the IR spectrum of a CCl_4 solution of **6,** evidence for the presence of an isomer **6a** is given by the OH absorption at 3590 cm^{-1}. Due to its cyclobutenol structure, **6a,** however, is supposed to be thermally labile and to convert into **7** by the known electrocyclic ring-opening of cyclobutenols into unsaturated carbonyl compounds [10].

*Epiminoenone (Z)-***5.** Among the analytical data especially characteristic are the UV (low ε compared to (*E*)-**5**), and even more the *AB* system at 6.41 ppm in the ^{1}H-NMR showing the coupling constant (J = 12) typical of (*Z*)-enones. Finally, the structure is proven by the conversion of (*Z*)-**5** into (*E*)-**5** upon irradiation.

Methyl(Azepinylidenmethyl)acetoacetate **12.** Evidence for the structure of this non isolable compound was gathered from the NMR data of the photolysis solution. The ^{1}H-NMR shows 2*s* of CH_3 groups bonded to olefinic C-atoms (2.03, 2.09 ppm (CH_3(4), CH_3–C(7') and, particularly characteristic, 2*d* at 4.24 and 5.00 ppm (J = 8.8) of the H-atoms of the two adjacent tertiary C-atoms (C(2), *C*H–C(2)), which – in the ^{13}C-NMR – appear as 2*d* at 58.51 and 101.55 ppm, resp. Final structural proof was given by conversion of **12** into the pyrrole derivative **14,** a reaction proceeding in analogy to the recently reported conversion of **7** into **8** [5] (see *Scheme 1*). The analytical data of the isolated compound **14** confirm its structure beyond any doubt: thus, the structure of **12** is also established.

4. Discussion. – The structure of the photoproduct **6** suggests its formation *via* path ⓐ (*Scheme 3*): obviously, **6** may be regarded as an intramolecular trapping product of a photolytically generated azomethine ylide **a.** The *a priori* conceivable conversion of a primarily formed photoisomer **15** into **6** by a secondary photoprocess can be ruled out, as **6** is produced on photolysis also at $\lambda \geqq 347$ nm, whereas a photocyclization **15**→**6** should require excitation at shorter wave lengths (*cf.* [11]). It is remarkable that in the cycloaddition exclusively the carbonyl double bond is involved, whereas in the case of the epoxy- and methano-analogous compounds, cycloaddition was established to occur to either the enone moiety or to the C=C bond [12].

Scheme 3



The formation of the photoproduct **7** is not so clear. Although the ylide **a** represents a plausible precursor which may convert into **7** by a [1,4]-H-shift (path ⓑ), the experimental finding that the formation of **7** is favoured at $\lambda = 254$ nm suggests the involvement of at least one further path: thus, **7** may be the product of a direct H-shift (path ⓒ) or a secondary photoproduct of **6** (path ⓓ), as the conversion of **6** into **7** in CD_3CN is somewhat accelerated by irradiation at $\lambda = 254$ nm[3]).

The *N*-substituted compounds (*E*)-**4** and (*E*)-**5** do not lead to any product proving the intermediacy of azomethine ylides although the tendency of (*E*)-**4** to form such an intermediate on irradiation is indicated by the above-mentioned appearance of a blue colour. The sluggish photochemical reactivity of (*E*)-**4** may, therefore, be explained by the preferred closure of this ylide to the starting material.

The *N*-acylated derivatives (*E*)-**5** and (*Z*)-**5** equilibrate rapidly with their double bond isomers, so that one cannot decide whether the slower rearrangements to **12** and **13** proceed from the (*E*)- or (*Z*)-isomer or from both; moreover, based on the results of the photolyses, it is not possible to state whether the formation of these two products is due to a direct acyl- and H-shift, respectively, or to a rearrangement of a photolytically generated azomethine ylide.

5. Conclusion. – By the present study it has been shown that the photochemistry of the epimino-enones (*E*)-**3** to (*E*)-**5** is strongly influenced by the *N*-substitution and that, contrary to the thermal behaviour, the photochemical behaviour differs from that of the epoxy- and methano-analogous compounds.

The elemental analyses and NMR and mass spectra were carried out by the analytical department of the ETHZ. The author is indebted to the following persons for their help: Miss *B. Brandenberg*, Mr. *F. Fehr*, and Mr. *M. Langenauer* (NMR), Mrs. *L. Golgowski* and Prof. *J. Seibl* (MS), and Mr. *D. Manser* (elemental analyses).

Experimental Part

1. *General.* See [13]. For photolysis experiments, a *Hanovia* Hg low pressure lamp *TNM 15/32* (lamp *A*) or a *Philips* 125 W Hg medium pressure lamp *HPK* (lamp *B*) was used. The lamps were placed in a quartz or *Pyrex* jacket cooled by running water; for irradiations at $\lambda = \geqq 347$ nm, the *Pyrex* cooling jacket was provided with an additional, *ca.* 1 cm wide mantle containing a filter soln. (750 g of NaBr and 8 g of $Pb(NO_3)_2$ in 1 l of H_2O); in the experiments at temp. below 0°, a cooling jacket was used surrounded by an evacuated mantle. All irradiations were carried out under Ar in quartz or *Pyrex* tubes placed nearby the jacket. For temp. control, both the tubes and the jackets were immersed in a cooling bath. Small-scale experiments were carried out in 5-mm standard NMR tubes; at a larger scale, a 15-mm tube provided with a magnetic bar was used.

2. *Photolysis of (*E*)-***3***.* At irradiation (lamp *B*, *Pyrex*) of a soln. of 1.08 g (5.2 mmol) of (*E*)-**3** in 4 ml of dry CH_3CN at −30°, 730 mg (68%) of *4,6,10,10-tetramethyl-5-oxa-11-azatricyclo[4.4.1.0^{1,4}]undec-2-ene* (**6**) were isolated by filtration. Colourless crystals, m.p. 93–5° (dec.). IR (KBr): 3180*s* (br.), 3070*m*, 3020*s*, 2970*s*, 2940*s*, 2870*s*, 1670*w*, 1610*w*, 1460*m*, 1450*m*, 1440*m*, 1400*w*, 1385*s*, 1360*s*, 1335*m*, 1290*m*, 1275*m*, 1230*w*, 1200*m*, 1160*s*, 1130*s*, 1090*s*, 1070*m*, 1050*w*, 960*m*, 940*m*, 930*s*, 880*m*, 860*m*, 815*m*, 775*m*, 750*s*. IR(CCl_4): 3590*m*, 3200*m* (br.), 3070*m*, 3010*m*, 2950*s*, 2930*s* (sh), 2870*s*, 1600*w*, 1460*m*, 1375*s*, 1355*s*, 1330*m*, 1285*w*, 1265*m*, 1225*w*, 1180*m*, 1155*s*, 1125*s*, 1095*s*, 1080*s*, 1055*m*, 955*m*, 920*s*. ^{1}H-NMR (CD_2Cl_2, 237K): 0.89, 1.06, 1.10, 1.48 (4*s*, $2CH_3$–C(10), CH_3–C(4), CH_3–C(6)); 1.00–1.97 (*m*, CH_2(7), CH_2(8), CH_2(9)); 5.65, 5.87 (2*d*, $J = 5.4$, H–C(2), H–C(3)); 5.98 (br. *s*, NH). ^{13}C-NMR (CD_2Cl_2, 237K): 19.07, 23.18, 27.45, 27.64 (4*q*, $2CH_3$–C(10), CH_3–C(4), CH_3–C(6));

[3]) The latter pathway cannot be exluded since it was not possible to exactly determine the UV spectrum of **6**: instead of the expected endabsorption, solutions of **6** showed a distinct absorption maximum at $\lambda = 227$ nm ($\varepsilon = 2700$), the shape of the spectrum changing within a few hours. These facts make it more probable that the observed absorption is due to other species resulting from transformation of **6** into *e.g.* **7**.

18.32, 34.33, 37.26 (3*t*, C(7), C(8), C(9)); 30.81 (*s*, C(10)); 53.19 (*s*, C(1)); 67.98 (*s*, C(4)); 97.93 (*s*, C(6)); 131.29, 135.75 (2*d*, C(2), C(3)). MS: 207 (13, M^+, $C_{13}H_{21}NO$), 192 (15), 189 (11), 174 (28), 165 (13), *164* (100), 150 (22), 149 (14), 136 (13), 135 (21), 134 (10), 123 (58), 122 (14), 107 (17), 91 (12), 84 (13), 79 (22), 70 (21), 57 (14), 55 (14), 53 (11), 43 (28), 42 (12), 41 (28), 39 (14). Anal. calc. for $C_{13}H_{21}NO$ (207.32): C 75.32, H 10.21, N 6.76; found: C 75.06, H 10.11, N 6.76.

*4-(3,4,5,6-Tetrahydro-3,3,7-trimethyl-2*H*-azepin-2-yliden)butan-2-one* (**7**). NMR data, see [5].

3. *Photolysis of* (E)-**4.** Irradiation (lamp *B*, *Pyrex*) of a soln. of 0.52 g (2.3 mmol) of (*E*)-**4** in dry CH_3CN (5 ml) for 24 h followed by chromatography (CH_2Cl_2/AcOEt 9:1) afforded 80 mg (15%) of *6,6-dimethylundeca-2,5,10-trione* (**10**). Spectroscopic data, see [8].

4-(1,3,3-Trimethyl-7-methylidenazepan-2-yliden)butan-2-one (**9**). NMR data, see [5].

4. *Photolysis of* (*E*)-**5.** 4.1. *At* $\lambda \geqq 347$ *nm.* A soln. of 800 mg (3 mmol) of (*E*)-**5** in 200 ml of dry CH_3CN was irradiated (lamp *B*, filter soln.) for 20 h at r.t. The solvent was distilled at ordinary pressure and the residue purified twice by chromatography (CH_2Cl_2/AcOEt 9:1; Et_2O/petroleum ether (40–60°) 8:2) yielding 230 mg (29%) of **14.**

4.2. *At* $\lambda > 280$ *nm.* Irradiation (lamp *B*, *Pyrex*) of a soln. of 927 mg (3.5 mmol) of (*E*)-**5** in 2.5 ml of dry CH_3CN for 1 h followed by chromatography (pentane/hexane/Et_2O 1:1:1) yielded 750 mg of (*E*)-**5** and 150 mg (85% based on unrecovered (*E*)-**5**) of *(3Z)-4-(1,2-methoxycarbonylepimino-2,6,6-trimethylcyclohexyl)but-3-en-2-on* (= methyl 2,2,6-trimethyl-1-((*Z*)-3-oxobut-1-enyl)-7-azabicyclo[4.1.0]heptane-7-carboxylate; (*Z*)-**5**). Colourless oil, b.p. 120°/0.01 mbar (dec.). UV (1.042 mg in 20 ml of pentane): 227 (6260). IR: 3020*w*, 2990*m*, 2940*s*, 2860*m*, 1700*s*, 1605*m*, 1440*m*, 1425*s*, 1400*m*, 1370*m*, 1350*m*, 1260*s*, 1230*m*, 1190*m*, 1155*s*, 1100*m*, 1040*w*, 1020*m*, 1005*w*, 960*w*. ^{1}H-NMR (CD_3CN, 238K): 0.94, 1.00 (2*s*, $2CH_3$–C(6'), CH_3–C(2')); 1.00–1.90 (*m*, CH_2(3'), CH_2(4'), CH_2(5')); 2.16 (*s*, CH_3(1)); 3.56 (*s*, CH_3O); 6.41 (*AB*, $J = 12$, $\delta_A = 6.38$, $\delta_B = 6.44$, H–C(3), H–C(4)). MS: 265 (6, M^+, $C_{15}H_{23}NO_3$), 206 (10), 182 (12), 163 (11), 154 (11), 150 (18), 148 (12), 135 (16), 124 (11), *123* (100), 122 (12), 69 (10), 55 (11), 43 (41), 41 (21). Anal. calc. for $C_{15}H_{23}NO_3$: C 67.90, H 8.74, N 5.28; found: C 68.27, H 8.63, N 4.90.

*Methyl 3-Oxo-2-[(3,4,5,6-tetrahydro-3,3,7-trimethyl-2*H*-azepin-2-yliden)methyl]butyrate* (**12**). ^{1}H-NMR (CD_3CN, 237K): 1.00, 1.04 (2*s*, $2CH_3$–C(3')); 1.00–2.15 (*m*, CH_2(4'), CH_2(5'), CH_2(6')); 2.03, 2.09 (2*s*, CH_3–C(7'), CH_3(4)); 3.60 (*s*, CH_3O)); 4.24 (*d*, $J = 8.8$, H–C(2)); 5.00 (*d*, $J = 8.8$, CH–C(2)). ^{13}C-NMR (CD_3CN, 237K): 20.02 (*t*, C(5')); 27.59, 27.97, 28.62, 29.14 (4*q*, $2CH_3$–C(3'), CH_3–C(7'), CH_3(4)); 35.06 (*t*, C(4')); 36.65 (*s*, C(3')); 44.52 (*t*, C(6')); 53.15 (*q*, CH_3O); 58.51 (*d*, C(2)); 101.55 (*d*, CH–C(2)); 160.04, 171.03, 173.89 (3*s*, C(2'), C(7'), CO_2CH_3); 203.93 (*s*, C = O).

Methyl 3,3-Dimethyl-7-methyliden-2-(3-oxobutyliden)azepane-1-carboxylate (**13**). NMR data, see [5].

Methyl 5-(1,1-Dimethyl-5-oxohexyl)-2-methylpyrrole-3-carboxylate (**14**). Colourless oil, b.p. 200°/0.008 mbar. UV (2.433 mg in 20 ml of pentane): 226 (6400), 265 (4590). IR ($CHCl_3$): 3460*m*, 3330*m* (br.), 3040*w* (sh), 3000*m*, 2960*s*, 2920*m* (sh), 2880*m* (sh), 1695*s*, 1590*m*, 1510*w*, 1440*s*, 1360*s*, 1340*m* (sh), 1300*w*, 1165*m* (sh), 1105*m*, 1075*s*. ^{1}H-NMR: 1.18 (*s*, $2CH_3$–C(1')); 1.38–1.46 (*m*, CH_2(2'), CH_2(3')); 2.04 (*s*, CH_3–C(5')); 2.33 (*t*, $J = 7$, CH_2(4')); 2.44 (*s*, CH_3–C(2)); 3.71 (*s*, CH_3O); 6.16 (*d*, $J = 3$, H–C(4)); 9.12 (br. *s*, NH). ^{13}C-NMR: 13.13 (*q*, CH_3–C(2)); 19.04 (*t*, C(3')); 28.35 (*q*, $2CH_3$–C(1')); 29.84 (*q*, CH_3–C(5')); 34.40 (*s*, C(1')); 41.80, 43.57 (2*t*, C(2'), C(4')); 50.62 (*q*, CH_3O); 105.29 (*d*, C(4)); 110.54 (*s*, C(3)); 134.66, 138.36 (2*s*, C(2), C(5)); 166.47 (*s*, CO_2CH_3); 209.84 (*s*, C = O). MS: 265 (8, M^+, $C_{15}H_{23}NO_3$), 181 (12), *180* (100), 148 (10). Anal. calc. for $C_{15}H_{23}NO_3$ (265.33): C 67.90, H 8.74, N 5.28; found: C 67.45, H 6.64, N 5.18.

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