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Ring Opening of Cyclopropylketones Induced by Photochemical Electron Transfer

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Abstract: Depending on the substitution pattern of cyclopropylketones, the photochemically induced electron transfer of tertiary amines to cyclopropylketones leads either to the formation of 3-substituted cycloalkanones or to ring expanded products.

Radical ring closure has been intensively investigated as a method for the construction of organic compounds. Synthetic applications of the reverse process, radical ring opening, have received less attention. The physical organic chemistry of radical ring opening has been studied in details, particularly for carbocyclic system. Most of the reported measurements involve small rings, such as cyclopropylcarbinyl systems. The rate constant for ring opening of methylcyclopropylcarbinyl radical is about 10^8 s^{-1} at 25°C and the rate for the reverse process is about 10^4 s^{-1} . ¹ The cleavage of a cyclopropane conjugated to a ketone has been of considerable interest. This cleavage has been achieved by using electrolysis, ² samarium iodide, ³ alkali metal.⁴

As part of our interest in the development of useful sequences featuring the cyclopropylcarbinyl radical rearrangement, we have examined the photochemically induced electron transfer of tertiary amines to cyclopropylketones with the aim of obtaining 3-substituted cycloalkanones (path a) and/or ring expanded products (path b) under very mild conditions according to the mechanism outlined in Scheme I.

Scheme I: ring opening of cyclopropylketones



Secondly, we would like to report a further extension of the reaction of the photochemical electron transfer which can induce a fragmentation and a cyclization from

bicyclo[n.1.0]alkanones bearing an unsaturated alkyl side chain at C-4, able to produce bicyclic systems such as **F**.



Various bicyclo[n.1.0]alkanones 1-3, 5 4-5, 27 8-10, 5 26-28 5 were prepared according to literature procedures. Compounds 6 and 7 were synthesized by treatment of the corresponding allylic alcohol 6 with diiodomethane in the presence of samarium-mercury chloride. ⁷ The obtained alcohols were then oxidized with PCC in the presence of molecular sieves. ⁸



Initially we chose to examine the irradiation of the bicyclo[4.1.0]heptanone 1 at 254 nm in acetonitrile (5 x 10^{-2} M) in the presence of triethylamine (10 equivalents). Under these conditions two products were formed in low yields *i.e.* the expected ketone 11 (10 %) and the alcohol 11^{,9} (15 %).



In order to improve the yield of 11, the reaction conditions and the presence of additives were screened in some details. The addition of $LiClO_4$ was found to be quite beneficial. ¹⁰ In the presence of 1 equivalent of $LiClO_4$, and 10 equivalents of NEt3, the yield of ketone 11 was increased to 55 % and alcohol 11' was no longer detected ¹¹. The effect of $LiClO_4$ can be explained as follows.

On irradiating ketone 1 in the presence of triethylamine without $LiClO_4$, a fast electron transfer from the amine to the ketone takes place and leads to the formation of a contact ion radical pair G in acetonitrile ¹². This electron transfer is followed by the ring cleavage of the cyclopropane ring which produces the ion pair H-J'. The radical-anion H most probably has a Pk_a in the range of ~ 10 and the triethylamine radical-cation a Pk_a of ~8 in water. ¹³ Therefore the radical-anion H is basic enough to deprotonate the amine radical-cation. The proton transfer can take place if a contact ion pair is previously formed. ¹⁴ Radical I can then abstract an hydrogen atom from the solvent or from triethylamine to produce ketone 11. Ketone 11 can be reduced to the alcohol 11' by a second electron transfer either from the amino-radical J or from

a second molecule of triethylamine. We have to point out that without LiClO4 unindentified polymers were formed which are probably initiated by radicals I and/or J and propagated at the expense of 11.

Scheme II: photoinduced electron transfer between 1 and triethylamine



When $LiClO_4$ is present, the ketyl radical-anion counter ion $Et_3N_*^+$ is exchanged by Li^+ , producing a very tight ion pair 1'. ¹⁵ The proton transfer is delayed as the radical-anion and the amine radical-cation are dissociated by this counter-ion exchange.

Irradiation of ketones 2-10 at 254 nm in acetonitrile, in the presence of 10 equivalents of triethylamine and 1 equivalent of $LiClO_4$ in acetonitrile led to the results reported in Table I.

The bicyclo[4.1.0]heptanone 2 led exclusively to the formation of the corresponding 3-methylcyclohexanone 12 with a yield of 70 % at 70 % conversion. We have to point out that the photochemical electron transfer is possible either by exciting the ketone at 300 nm or by exciting the donor molecule (triethylamine) at 254 nm. ¹⁶ However, lower yieds in 12 were obtained when the irradiation of 2 was performed with triethylamine in ethanol at 254 nm or 300nm, ¹⁶ or in acetonitrile at 254 nm in sealed glass tube. ¹⁷

		°	hv NEt ₃	ů,		
Solvent	additive	2 NEt3	Conc	12 λ nm	Duration	Yield in %
EtOH	0	20 %	2 x 10-2 M	300	4 h	55 % 16
CH ₃ CN	0	5%	5 x 10 ⁻² M	254	10 h	40 % 17
CH ₃ CN	LiClO ₄	10 %	5 x 10 ⁻² M	254	2 h	70 % 11

Starting Material	Conversion	Products (Yield%)	
,	100%	Ĵ.	OH
	70%	11 (50%) 0 1 12 (70%)	11' (0%)
ů ,	60%	ů,	
CO ₂ Me	75%	13 (80%) 0 	
4 CO ₂ Me	80%	14 (60 %)	
G CO ₂ Me	90%		
	100%	0 CO ₂ Me 17 (65%)	
8	100%	18 (60%)	0 19 (trace)
g CO ₂ Me	100%	0 CO ₂ Me 20 (80%)	CO ₂ Me 21 (trace)
10	100%	о СО ₂ Ме) ₄ 22 (55%)	

TABLE I: Irradiation of bicyclo[n.1.0]alkanones in the presence of LiClO4

Thus, the irradiation of 3, in the presence of 10 equivalents of triethylamine and 1 equivalent of LiClO₄, led to the formation of 13 as a mixture of two isomers *trans/cis* in a ratio 1.8/1 with a yield of 80% at 60% conversion. When compounds 4 and 5 were irradiated, the corresponding 3-methylcycloalkanones 14 (*trans/cis* = 10/1) ¹⁸ and 15 (*trans/cis* = 5.7/1), ¹⁸ respectively, were isolated with a yield of 60 %.

The bicycloalkanone 6 and 7 that are substituted by an electron-withdrawing group at C-4 led to the formation of ring expanded cycloalkanone 16 (50 %) and 17 (65 %), respectively. Similarly, cyclooctanone 18 (60 %) was obtained by irradiation of the bicyclo[5.1.0]octanone 8 together with a trace of the 3-methylcycloheptanone 19 that was detected by GC/MS. ¹⁹ With compounds 9 and 10 the corresponding ring expanded β -ketoester 20 (80 %) and 22(55 %) were isolated.

The preferred regioselectivity of the ring opening depends on the substitution pattern of the bicycloalkanones and on its ring size. ²⁰ (Scheme I)

The radical-enolate intermediates of type **D'** arising from the cleavage of bond C(1)-C(n+2) (ring enlargement process) are more stable (3-4 kcal/mol if $R_2 = H$ and 11-14 kcal/mole if $R = CO_2Me$) ²¹ than the corresponding intermediate C'. The former is a secondary radical either substituted or not by an ester moiety, the latter is a primary radical. The ring enlargement can be explained by the fact that the C(1)-C(n+2) bond of the bicyclo{n.1.0]alkan-2-ones is weaker than that of bond C(1)-C(n+3). In the case of 1, 2, 3, 4 and 5, the C(1)-C(n+3) bond is cleaved preferentially due to stereoelectronic factor, the latter bond being better aligned with the π -system of the ketone radical-anion than bond C(1)-C(n+2). In the case of compound 6 and 7 the kinetic stereoelectronic factor does not compete with the highly favorable factor which makes the ring enlarged radical-anion intermediates highly stabilized by the carbonyl group. In compounds 8 and 9, the flexibility of the bicyclic carbon skeleton makes both the C(1)-C(7) and C(1)-C(8) bond capable of proper alignment with the π -system of the ketone radical-anion, thus leading to mixture of the corresponding methylcycloheptanones and ring-enlarged cyclooctanones.

The intramolecular trapping of the radical C' induced by the PET fragmentation of the bicyclo[n.1.0]alkanones was achieved through irradiation of the bicycloalkanones 26, 27 and 28. These compounds were synthesized by cyclopropanation of the 4-alkylcyclohexen-2-ones 22 according to Corey's method using trimethylsulfoxonium iodide. ⁵ The cyclopropanation of the 4-alkylcyclohexen-2-ones 23, 24 and 25 produced one major isomer in a ratio 95/5 (GC). Due to a Michael type addition of the trimethylsulfoxonium iodide on the ketone, the unsaturated alkyl side chain at C-4 and the cyclopropane group are in a *trans* relationship in the major isomer.



The irradiation of compounds 26, 27 and 28 in the presence of triethylamine (10 eq) and LiClO₄ (1 eq) in acetonitrile led to the formation of 29 (70%), 30 (53%) and 31 (15%), respectively (Table II). The formation of these bicyclic compounds showed, as expected, only the cleavage of the exocyclic cyclopropyl bond.

We have to point out that the irradiation of compound 26 at 300 nm in the presence of 4 equivalents of triethylamine, with or without $LiClO_4$ (1 eq) produced compound 29 with a yield of 28 %. ²³

Table II: irradiation of 5-alkylbicyclo[4.1.0]alkanones



Since the configuration at C-4 and C-5 in compounds 26, 27 and 28 is not affected during the course of the reaction, the relative configuration at the ring jonction is *trans* in compounds 29, 30 and 31.

The photoreductive cyclopropane ring opening of bicyclo[n.1.0]alkanones reveals that this reaction can be controlled by stereoelectronic factors and by the relative stabilities of the radical enolate anion intermediates C' and D' generated by the cleavage of bond C(1)-C(n+3) and C(1)-C(n+2) respectively. The latter factor depends on the ring size (n value) and on the substitution pattern. Furthermore, the intermediate radical can be trapped intramolecularly by an unsaturation.

Presently, we are investigating application of the cyclopropane fragmentation process, disclosed here, to the synthesis of natural products.

Experimental part

General methods

All experiments were run under an Ar atmosphere. ¹H NMR and ¹³C-NMR spectra were obtained with a Bruker AC 300 instrument at 300 MHz and 75 MHz respectively, in CDCl₃ (Me₄Si as internal standard). IR spectra were recorded on a Perkin-Elmer Infracord 137 spectrometer. Mass spectra were run on a Hewlett-Packard (El mode at 70 eV).

Flash chromatography was accomplished with Merck silicagel 0.043-0.063 nm.

Preparative irradiations were conducted in a merry-go-round type system equipped with 12 low pressure mercury Philips TUV 15 lamps (254 nm), using 10 mm 0.d. quartz tubes. Acetonitrile and triethylamine were distilled from CaH₂.

Cyclopropanation of cycloalken-2-ones. Synthesis of bicyclo[n.1.0]alkanones

To a suspension of sodium hydride (1.6 g, 67.6 mmol, 1.3 eq) in DMSO (90 mL) was added trimethylsulfoxonium iodide (14.9 g, 67.6 mmol, 1.3 eq). After 15 mn, a solution of enone (52.0 mmol, 1.0 eq) in DMSO (15 mL) was added dropwise and the reaction mixture was stirred at r. t. for 2 h and at 50°C for 1 h. Water was then added (150 mL). The reaction mixture was extracted with ether (3 x 10 mL). The organic phases were combined, dried over MgSO₄ and evaporated *in vacuo*. The bicyclo[n.1.0]alkanones were purified by distillation or by flash chromatography.

4, 6-Dimethylbicyclo[4.1.0]heptan-2-one 1 24

R_f: 0.32 (Pentane-Et₂O: 80/20). Yield: 40 %. IR: 1685; 1295; 1243 cm⁻¹. ¹H NMR: δ 0.88 (dd, 1H, J = 10.0 Hz, J = 5.0 Hz); 0.94 (d, 3H, J = 6.0 Hz); 1.20 (s, 3H); 1.34 (m, 1H); 1.40 (d, 1H, J = 12.5 Hz); 1.50-1.90 (m, 3H); 1.97 (dd, 1H, J = 13.1 Hz, J = 3.5 Hz); 2.35-2.40 (dd, 1H, J = 13.0 Hz, J = 3.5 Hz). ¹³C NMR: δ 17.9 (t); 21.9 (q); 23.4 (s); 24.5 (d); 24.8 (q); 33.5 (d); 37.2 (t); 44.8 (t); 208.8 (s). MS (CI, NH₃): m/z 156 (MNH₄+, 72); 139 (MH⁺,100).

Bicyclo[4.1.0]heptan-2-one 2 24

B.p.: 43° C (0.2 mm Hg). Yield: 80 %. IR: 1693, 1350, 1244 cm⁻¹. ¹H NMR: δ 0.84 (m. 1H); 0.93-1.03 (m, 1H); 1.29-1.53 (m, 4H); 1.68-1.87 (m, 3H); 1.96-2.10 (m, 1H).

¹³C NMR: δ 10.0 (t); 17.2 (d); 17.6 (t); 21.4 (t); 25.6 (d); 36.6 (t); 209.1 (s). MS: *m*/z 110 (M⁺, 84); 95 (58); 82 (44); 67 (92); 55 (84); 54 (100).

2-Butylbicyclo[4.1.0]heptanone 3

Rf: 0.4 (Hexane/AcOEt: 90/10). Yield: 90%. IR: 1690, 1465, 1360 cm⁻¹. ¹H NMR: δ 0.92-0.75 (m, 5H); 1.15-1.33 (m, 5H); 1.42-1.50 (m, 1H); 1.55-1.70 (m, 2H); 1.85-2.12 (m, 4H); 2.18-2.30 (m, 1H). ¹³C NMR: δ 13.9 (q); 16.9 (t); 18.8 (t); 21.9 (t); 22.6 (t); 24.0 (q); 29.2 (t); 34.0 (t); 37.2 (t); 209.6 (s). MS: *m*/*z* 166 (M⁺, 8); 151 (100); 137 (43); 123 (56); 95 (90); 67 (98); 55 (70).

Bicyclo[5.1.0]octan-2-one 8²⁵

R_f: 0.36 (Hexane/AcOEt: 80/20). Yield: 40%. IR: 1665, 1360 cm⁻¹. ¹H NMR: δ 1.05 (m, 1H); 1.13-1.30 (m, 2H); 1.85-2.03 (m, 7H); 2.30-2.45 (m, 2H). ¹³C NMR: δ 12.3 (t); 18.6 (d); 23.5 (t); 25.0 (t); 27.6 (t); 30.3 (d); 41.4 (t); 211.4 (s). MS: m/z 124 (M⁺, 67); 95 (39); 80 (100); 67 (60).

Methyl 2-oxobicyclo[5.1.0]octane-1-carboxylate 9

Prepared from the corresponding enone ²⁶

R_f: 0.30 (Hexane/AcOEt: 80/20). Yield: 50 %. IR: 1755, 1715, 1320, 1300 cm⁻¹. ¹H NMR: δ 0.50-0.70 (m, 1H); 1.20-1.30 (m, 1H); 1.30-1.50 (m, 2H); 1.50-1.60 (m, 1H); 1.70-2.00 (m, 3H); 2.35-2.50 (m, 1H); 2.50-2.60 (m, 1H); 2.80-3.00 (m, 1H); 3.70 (s, 3H). ¹³C NMR: δ 22.3 (t); 25.3 (d); 25.8 (t); 26.2 (t); 30.4 (t); 39.6 (s); 43.9 (t); 52.5 (q); 171.9 (s); 205.2 (s). Anal. Calcd for $C_{10}H_{14}O_3$: C, 65.91; H, 7.74. Found : C, 65.97; H, 7.69.

Methyl 2-oxobicyclo[6.1.0]nonane-1-carboxylate 10

Prepared from the corresponding enone ²⁶.

R_f: 0.24 (Hexane/AcOEt: 85/15). IR: 1760, 1720, 1375, 1320 cm⁻¹. ¹H NMR: δ 0.50-0.75 (m, 1H); 1.20-1.35 (m, 1H); 1.35-2.15 (m, 9H); 2.30-2.45 (m, 1H); 3.10-3.30 (m, 1H); 3.75 (s, 3H). ¹³C NMR: δ 19.0 (t); 24.9 (t); 26.6 (t); 27.4 (t); 28.5 (t); 30.6 (d); 39.5 (s); 45.0 (t); 52.9 (q); 171.7 (s); 207.0 (s). MS: m/z 196 (M⁺, 30); 166 (65); 137 (60); 81 (70); 55 (100).

5-(Prop-2-enyl)bicyclo[4.1.0]heptan-2-one 26

R_f: 0.31 (Hexane/AcOEt: 65/35). Yield: 54 %. IR: 1675, 1430, 1400 cm-1. ¹H NMR: δ 1.00-1.25 (m, 2H); 1.45-1.90 (m, 4H); 1.90-2.30 (m, 5H); 4.90-5.15 (m, 2H); 5.65-5.95 (m, 1H). ¹³C NMR: δ 12.5 (t); 23.5 (t); 23.8 (d); 25.4 (d); 31.4 (d); 32.8 (t); 38.9 (t); 116.6 (t); 136.4 (d); 209.4 (s). MS: *m*/*z* 150 (M⁺, 15); 122 (22); 109 (95); 91 (22); 81 (100); 79 (61); 67 (75); 55 (42). Exact Mass Calcd for C₁₀H₁₄O: 150.10446. Found: 150.10445.

5-(Prop-2-ynyl)bicyclo[4.1.0]heptan-2-one 27

R_f: 0.36 (Hexane/AcOEt: 50/50). Yield: 50 %. IR: 1685, 1350 cm⁻¹. ¹H NMR: δ 1.10-1.28 (m, 2H); 1.67-1.90 (m, 4H); 2.09 (t, 1H, J = 2.4 Hz); 2.11-2.22 (m, 2H); 2.24-2.43 (m, 3H). ¹³C NMR: δ 12.2 (t); 23.1 (d); 24.2 (t); 24.7 (t); 25.3 (d); 31.2 (d); 32.4 (t); 69.8 (d); 82.0 (s); 208.5 (s). MS (CI, NH₃): m/z 166 (MNH₄⁺, 20); 149 (MH⁺, 100); 109 (15); 91 (20). Anal. Calcd. for C₁₀H₁₂O: C, 81.04; H, 8.16. Found: C, 81.06; H, 8.19.

5-(But-3-enyl)bicyclo[4.1.0]heptan-2-one 28

R_f: 0.35 (Hexane/AcOEt: 75/25). Yield: 56 %. IR: 1685, 1630, 1440 cm^{-1.} ¹H NMR: δ 1.10-1.35 (m, 2H); 140-1.70 (m, 4H); 1.70-1.90 (m, 2H); 1.95-2.10 (m, 2H); 2.10-2.30 (m, 3H); 4.85-5.15 (m, 2H); 5.70-5.95 (m, 1H). ¹³C NMR: δ 13.4 (t); 24.7 (t); 24.9 (d); 26.2 (d); 32.2 (d); 33.3 (t); 33.8 (t); 34.4 (t); 115.6 (t); 138.9 (d); 209.8 (s). MS: m/z 164 (M⁺, 3); 149 (10); 136 (13); 122 (18); 109 (24); 94 (61). Anal. Calcd. for C₁₁H₁₆O: C, 80.43 ; H, 9.82. Found: C, 80.55; H.9.78.

Cyclopropanation of methyl 3-hydroxycycloalk-1-ene-1-carboxylate

To a solution of mercuric chloride (0.4 g, 1.4 mmol. 1.0 eq) in THF (30 mL) is added metallic samarium (2.1 g, 13.8 mmol, 10.0 eq) in THF (30 mL). After 10 mn, methyl 3-hydroxycycloalk-1-ene-1-carboxylate (3.5 mmol, 2.5 eq) is added. The reaction mixture is cooled to -78° C and diiodomethane (3.7 g, 13.8 mmol, 10.0 eq) is added dropwise. After 2 h at r. t., an aqueous solution of K₂CO₃ is added (10 mL) followed by the addition of ether (3 x 10 mL). The organic phases were combined and dried (MgSO₄), filtered and concentrated *in vacuo*. The residue is purified by flash chromatography.

Methyl 4-hydroxybicyclo[3.1.0]hexane-1-carboxylate 6' As the product was difficult to purify, it was oxidized directly.

Methyl 4-hydroxybicyclo[4.1.0]heptane-1-carboxylate 7'

R_f: 0.39 (Hexane/AcOEt: 50/50). Yield: 80 %. IR: 1715, 1745, 1295 cm⁻¹. ¹H NMR: δ 0.93 (m, 1H); 1.02-2.57 (m, 9H); 3.66 (s, 3H); 4.18-4.29 (m, 1H). ¹³C NMR: δ 17.4 (t); 19.6 (t); 23.6 (t); 25.7 (s); 28.0 (d); 29.3 (t); 52.1 (q); 65.7 (d); 175.0 (s). MS: *m*/z 170 (M⁺, 2); 152 (4); 138 (60); 127 (16); 110 (100); 93 (36); 82 (66).

Oxydation of 6' and 7'

To a suspension of molecular sieves 5 Å (0.5 g) and PCC (0.3 g, 1.5 mmol, 1.5 eq) in CH_2Cl_2 (2.5 mL) at r. t., was added rapidly a solution of the alcohol **6'** or **7'** (1.0 mmol, 1.0 eq) in CH_2Cl_2 (1.0 mL). After 24 h, the reaction mixture was diluted with ether (5 mL) and

filtered on florisil. The solvent was evaporated and the residue purified by flash chromatography.

Methyl 4-oxobicyclo[3.1.0]hexane-1-carboxylate 6

R_f: 0.39 (Hexane/AcOEt: 70/30). Yield: 58 %. IR: 1730, 1370, 1265 cm⁻¹. ¹H NMR: δ 1.30-1.40 (m, 1H); 1.90-2.00 (m, 1H); 2.10-2.40 (m, 4H); 2.45-2.70 (m, 1H); 3.75 (s, 3H). ¹³C NMR: δ 20.0 (t); 22.6 (t); 33.0 (t); 33.4 (s); 36.4 (d); 52.3 (q); 172.2 (s); 210.8 (s). MS: *m/z* 154 (M⁺, 60); 126 (100); 123 (35); 100 (40); 98 (25). Anal. Calcd for C₈H₁₀O₃: C, 62.32; H, 6.53. Found: C, 62.38; H, 6.59.

Methyl 5-oxobicyclo[4.1.0]heptane-1-carboxylate 7

R_f: 0.29 (Pentane/Et₂O: 60/40). Yield: 60 %. IR: 1720, 1690, 1265 cm⁻¹. ¹H NMR: δ 1.40-1.60 (m, 2H); 1.60-1.70 (m, 1H); 1.70-1.85 (m, 1H); 1.90-2.10 (m, 1H); 2.15-2.40 (m, 4H); 3.70 (s, 3H). ¹³C NMR: δ 16.3 (t); 17.5 (t); 21.2 (t); 25.7 (d); 35.1 (s); 38.2 (t); 53.2 (q); 170.8 (s); 202.5 (s). MS: m/z 168 (M⁺, 33); 140 (40); 121 (18); 100 (45); 81 (65); 55 (100). Anal. Calcd for C₉H₁₂O₃: C, 64.27; H, 7.19. Found: C, 64.32; H, 7.10.

Compounds 4 and 5 were prepared from methyl 2-diazo-3-oxoalkenoate 27

Methyl 2-oxobicyclo[3.1.0] hexane-1-carboxylate 4²⁷

This compound was prepared from methyl 2-diazo-3-oxohept-6-enoate.

IR: 1760; 1730; 1380 cm⁻¹. ¹H NMR: δ 1.40-150 (m, 1H); 1.95-2.35 (m, 5H); 2.55-2.70 (m, 1H); 3.75 (s, 3H). ¹³C NMR: δ 20.9 (t); 22.1 (t); 33.1 (d); 33.6 (t); 37.5 (s); 52.2 (q); 168.8 (s); 206.7 (s). MS: *m*/*z* 154 (M⁺, 75); 139 (10); 126 (87); 113 (100); 98(35).

Methyl 2-oxobicyclo[4.1.0]heptane-1-carboxylate 5²⁷

This compound was prepared from methyl 2-diazo-3-oxoöct-7-enoate. IR: 1720, 1690, 1430, 1265 cm⁻¹. ¹H NMR: δ 1.30-1.40 (m, 1H); 1.40-2.50 (m, 8H); 3.72 (s, 3H). ¹³C NMR: δ 16.3 (t); 17.5 (t); 21.3 (t); 25.7 (d); 35.1 (s); 38.3 (t); 52.3 (q); 170.6 (s); 202.5 (s). MS: *m*/z 168 (M⁺, 45); 136 (100); 108 (90); 80 (55).

Irradiation of the bicyclo[4.1.0]alkanones

A solution of bicyclo[4.1.0]alkanone (0.7 mmol, 1.0 eq) in dry acetonitrile (5 x 10^{-2} M) of triethylamine (10.0 eq) and lithium perchlorate (1.0 eq) was irradiated at 254 nm. After 5 h the solvent was evaporated and the residue was distilled or purified by flash chromatography.

3,3,5-Trimethylcyclohexanone 11²⁸

 $\begin{array}{l} R_f: \ 0.32 \ (\text{Pentane/Et}_2\text{O}: \ 80/20). \ Yield: \ 50 \ \%. \ IR: \ 1705, \ 1450, \ 1270 \ cm^{-1}. \ ^1H \ NMR: \ \delta \ 0.89 \ (s, \ 3H); \ 1.02 \ (d, \ 3H, \ J = 7.4 \ Hz); \ 1.06 \ (s, \ 3H); \ 1.30 \ (ddd, \ 1H, \ J = 12.0 \ Hz, \ J = 13.0 \ Hz); \ 1.53-1.65 \ (m, \ 1H); \ 1.80-1.92 \ (dd, \ 1H, \ J = 13.0 \ Hz, \ J = 3.5 \ Hz); \ 2.00-2.25 \ (m, \ 2H); \ 2.30-2.40 \ (m, \ 2H). \ ^{13}C \ NMR: \ \delta \ 22.4 \ (q); \ 25.7 \ (q); \ 29.6 \ (d); \ 32.1 \ (q); \ 35.3 \ (s); \ 47.2 \ (t); \ 49.2 \ (t); \ 54.1 \ (t); \ 211.9 \ (s). \ MS \ (CI, \ NH_3): \ m/z \ 158 \ (MNH_4^+, \ 100); \ 141 \ (50); \ 125 \ (30); \ 110 \ (50). \end{array}$

This compound has been synthesized by addition of lithium methylcuprate on 3,5-dimethylcyclohex-2-en-1-one.

3,3,5-Trimethylcyclohexanol 11'

R_f: 0.29 (Pentane/Et₂O: 60/40). Yield: 15 %. IR = 3400, 1210, 760 cm^{-1. 1}H NMR: δ 0.88 (s, 3H); 0.89 (d, 3H, J = 5.7 Hz); 1.11 (s, 3H); 1.00-2.10 (m, 8H); 4.16 (m, 1H). ¹³C NMR: δ 22.6 (q); 22.8 (q); 28.2 (d); 30.7 (s); 34.1 (q); 41.6 (t); 44.8 (t); 48.5 (t); 68.3 (d). MS: *m/z* 142 (M⁺, 1.5); 124 (16); 109 (100; 96 (16); 91 (17); 83 (27).

3-Methylcyclohexanone 12²⁸

R_f: 0.39 (Hexane/ACOEt: 50/50). Yield: 70 %. IR: 1715, 1450, 1270 cm⁻¹. ¹H NMR: δ 1.00 (d, 3H, J = 6.0 Hz); 1.10-2.70 (m, 9H). ¹³C NMR: δ 22.1 (q); 25.4 (t); 33.4 (t); 34.3 (d); 41.2 (t); 50.0 (t); 211.6 (s). MS: m/z 112 (M⁺, 72); 97 (23); 69 (100); 56 (33). This product has been synthesized by addition of lithium methylcuprate to cyclohexenone.

2-Butyl-3-methylcyclohexanone 13

Rf: 0.45 (Hexane/AcOEt; 90/10). Yield: 80%. Two isomers (*trans/cis*: 65/35). ¹H NMR: Minor isomer: δ 0.75 (d, 3H, J = 6.0 Hz). Major isomer: δ 0.95 (d, 3H, J = 6.5 Hz). Both isomer δ : 0.80 (t, 3H, J = 7.0 Hz); 1.02-1.30 (m, 5H); 1.33-1.96 (m, 7H); 2.10-2.34 (m, 2H). ¹³C NMR: Major isomer: δ 13.8 (q); 20.3 (q); 22.9 (t); 25.2 (t); 26.6 (t); 29.4 (t); 32.7 (t); 38.1 (d); 41.2 (t); 57.2 (d); 213.2 (s). MS: *m/z* 168 (M⁺, 5); 125 (10); 112 (49); 97 (100).

Methyl 5-methyl-2-oxocyclopentane-1-carboxylate 14 29,30

 R_{f} : 0.5 (Hexane/Et₂O: 90/10). Yield: 60 %. IR: 1760, 1200 cm⁻¹. ¹H NMR: δ 1.15 (d, 3H, J = 6.5 Hz); 1.40-1.60 (m, 1H); 2.10-2.70 (m, 4H); 2.80 (d, 1H, J = 11.0 Hz); 3.76 (s, 3H). ¹³C NMR: δ 19.1 (q); 29.2 (t); 36.2 (d); 38.6 (t); 52.2 (q); 62.8 (d); 169.5 (s); 211.7 (s). MS (CI, NH₃): *m/z* 162 (MNH₄⁺, 32); 145 (MH⁺, 32); 125 (48); 100 (100).

Methyl 6-methyl-2-oxocyclohexane-1-carboxylate 15 30

 R_f : 0.39 (Hexane/ACOEt: 70/30). Yield: 60 %. IR: 1740, 1705, 1645, 1435 cm⁻¹. ¹H NMR: δ 1.03 (d, 3H, J = 6.5 Hz); 1.05-2.50 (m, 7H); 3.05 (d, 1H, J = 12.0 Hz); 3.76 (s, 3H).

¹³C NMR: δ 20.9 (q); 25.0 (t); 32.4 (t); 36.6 (d); 40.9 (t); 51.9 (q); 65.0 (d); 170.2 (s); 206.0 (s). MS: *m*/*z* 170 (M⁺, 15); 155 (42); 138 (46); 123 (100).

Methyl 4-oxocyclohexane-1-carboxylate 16

Yield: 50 %. IR: 1735, 1715 cm⁻¹. ¹H NMR: δ 1.00-2.80 (m, 9H); 3.80 (s, 3H). MS: *m*/z 156 (50); 125 (40); 100 (100); 96 (60).

Methyl 4-oxocycloheptane-1-carboxylate 17 31

R_f: 0.21 (Hexane/AcOEt: 70/30). Yield: 65 %. IR: 1720, 1700, 1265 cm⁻¹. ¹H NMR: δ 1.40-2.40 (m, 8H); 240-2.70 (m, 3H); 3.67 (s, 3H). ¹³C NMR: δ 23.0 (t); 26.9 (t); 29.2 (t); 42.1 (t); 44.0 (t); 46.9 (d); 52.4 (q); 176.0 (s); 214.2 (s). MS: *m/z* 170 (M⁺, 45); 139 (45); 111 (89); 55 (100).

Cycloöctanone 18

Yield: 60 %. B.p.: 193-195°C. IR: 1685 cm⁻¹. ¹H NMR: δ 1.31-1.43 (m, 2H); 1.49-1.62 (m, 4H); 1.81-1.94 (m, 4H); 2.35-2.46 (m, 4H). ¹³C NMR: δ 24.6 (t); 25.5 (2t); 27.0 (2t); 41.8 (2t); 217.9 (s). MS: *m/z* 216 (M⁺, 20): 111 (10); 98 (10); 83 (38). This compound was compared with an authentic sample.

3-Methylcycloheptanone 19

IR: 1690, 1450 cm⁻¹. ¹H NMR: δ 1.00 (d, 3H, J = 6.7 Hz); 1.20-2.00 (m, 7H); 2.30-2.60 (m, 4H). ¹³C NMR: δ 23.4 (q); 24.1 (t); 28.4 (t); 31.1 (d); 39.1 (t); 43.9 (t); 51.6 (t); 214.2 (s). MS: *m*/*z* 126 (M⁺, 27); 111 (11); 98 (50); 82 (74); 69 (100); 55 (49).

This product has been synthesized by addition of lithium methylcuprate to cycloheptenone.

Methyl 2-oxocyclooctane-1-carboxylate 20

Yield: 80 %. IR: 1750, 1705, 1640 cm⁻¹. ¹H NMR: δ 1.30-2.70 (m, 12H); 3.60 (m, 1H); 3.70 (s, 3H). ¹³C NMR: δ 23.8 (t); 25.3 (t); 26.4 (t); 28.6 (t); 32.1 (t); 41.7 (t); 51.3 (q); 56.6 (d); 170.4 (s); 211.9 (s). MS: *m/z* 184 (M⁺, 60); 152 (100); 141 (15); 124 (65); 113 (67); 98 (59); 87 (100).

Methyl 7-methyl-2-oxocycloheptane-1-carboxylate 21

Ratio *cis/trans*: 35/65 determined by ¹H NMR. R_f: 0.4 (Hexane/AcOEt: 70/30). IR: 1740, 1705, 1635 cm⁻¹. ¹H NMR. *Cis* isomer: δ 1.02 (d, 3H, J = 6.7 Hz); 2.70-3.00 (m, 1H); 3.80 (s, 3H); *Trans* isomer: δ 1.07 (d, 3H, J = 7.1 Hz); 3.20 (d, 1H, J = 10.0 Hz,); 3.75 (s, 3H); Both isomers: δ 1.35-2.70 (m, 9H). ¹³C NMR: δ 20.9 (q); 25.0 (t); 32.4 (t); 35.4 (t); 36.6 (d); 41.0 (t); 52.0 (q); 65.0 (d); 170.2 (s); 204.0 (s).

Methyl 2-oxocyclononane-1-carboxylate 22

 $R_f = 0.21$ (Hexane/AcOEt: 70/30). Yield: 55 %. IR: 1735, 1700, 1635 cm⁻¹. ¹H NMR: δ 1.30-2.70 (m, 14H); 3.50-3.60 (m, 1H); 3.70 (s, 3H). 13 C NMR: δ 23.9 (t); 24.3 (t); 24.6 (t); 25.0 (t); 25.9 (t); 26.9 (t); 31.4 (t); 51.5 (q); 58.5 (d); 176.0 (s ; 211.7 (s). MS: m/z 198 (M⁺, 28); 167 (17); 166 (16); 110 (28); 94 (45).

8-Methylbicyclo[4.3.0]nonan-3-one 29

Rf: 0.56 (Pentane/Et₂O: 50/50). Yield: 70 %. Two isomers in a ratio: 5.5/1 (determined by ¹H NMR). IR: 1700, 1440, 1410 cm⁻¹. ¹H NMR. Major isomer: δ 1.00 (d, 3H, J = 7.0 Hz); Minor isomer: δ 1.05 (d, 3H, J = 7.0 Hz); Both isomers: δ 1.30-1.70 (m, 6H); 2.00-2.40 (m, 6H); 2.50-2.55 (m, 1H). ¹³C NMR. Major isomer: δ 26.8 (q); 33.3 (t); 35.8 (d); 43.4 (t); 43.7 (t); 44.6 (t); 49.1 (d); 46.5 (d); 51.1 (t); 215.8 (s). Minor isomer δ : 27.0 (q); 33.5 (t); 35.1 (d); 46.8 (d); 51.5 (t); 216.2 (s). MS: m/z 152 (M+, 85); 108 (100); 95 (75); 66 (50). Anal. Calcd for C₁₀H₁₆O; C, 78.89; H, 10.59. Found: C, 78.85; H, 10.63.

8-Methylenebicyclo[4.3.0]nonan-3-one 30

 R_{f} : 0.61 (Pentane/Et₂O: 90/10). Yield: 53 %. IR: 1710, 1655, 1425 cm⁻¹. ¹H NMR: δ 1.40-2.70 (m, 12H); 4.85-4.95 (m, 2H). ¹³C NMR: δ 29.3 (t); 37.8 (t); 38.4 (t); 39.4 (t); 40.8 (d); 41.2 (d); 42.7 (t); 106.6 (t); 150.2 (s); 211.8 (s). MS: m/z 150 (M+, 100); 122 (17); 106 (79); 93 (68); 79 (94). Anal. Calcd for $C_{10}H_{14}O$: C, 79.95; H, 9.39. Found: C, 79.87; H, 9.41.

9-Methylbicyclo/4.4.0]decan-3-one 31

 $R_f;$ 0.45 (Pentane/Et_2O: 70/30). Yield: 15 %. Two isomers in a ratio: 2/1 (determined by ¹H NMR). IR: 1705, 1445 cm⁻¹. ¹H NMR. Major isomer: δ 0.91 (d, 3H, J = 6.5 Hz). Minor isomer: δ 0.98 (d, 3H, J = 7.0 Hz). Both isomer: δ 1.20-2.50 (m, 15H). ¹³C NMR. Major isomer: δ 22.4 (q); 31.9 (d); 32.5 (t); 33.2 (t); 34.7 (t); 41.2 (d); 41.5 (t); 42.8 (t); 43.1 (d); 48.5 (t); 211.6 (s). Minor isomer: δ 22.2 (q); 31.4 (d); 32.6 (d); 33.5 (t); 34.5 (t); 40.9 (d); 41.7 (t); 42.9 (d); 43.4 (d); 48.7 (t); 211.7 (s). Anal. Calcd. for $C_{11}H_{18}O$; C, 79.46; H, 10.91. Found: C, 79.53; H, 10.97.

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