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Synthesis of Alkylidene Cyclopentenones. Enolization of 4-substituted Cyclopent-4-ene-1,3-diones

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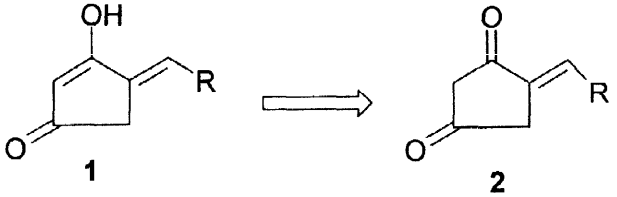
Abstract: The regioselective enolization of 4-substituted cyclopentene-1,3-diones **3a-e** is investigated under basic and acidic conditions. Enols **1** and enolethers **6**, **7** are formed with the simultaneous endocyclic double bond migration in the side chain.

Within the past ten years the synthesis of oxygenated alkylidene cyclopentenones such as sarkomycin,[1] methylenomycin A and B,[2] pentenomycin,[3] the marine eicosanoids clavulone,[4] chlorovulone[5] and punaglandins[6] has been a subject of intensive investigations. The biological importance and great structural diversity of cyclopentanoid natural products have made these compounds valuable synthetic targets.[7] However, all of them concern the synthesis of cross conjugated dienone systems.

We wish to describe a new method that provides an efficient access to highly functionalized alkylidene hydroxycyclopentenones - derivatives of 3-hydroxy-4-alkylidenecyclopent-2-enone **1** - which appear to be potentially useful building blocks in organic synthesis, and which may be regarded as an enolic form of 4-alkylidencyclopentan-1,3-dione **2**.



Enols **1a-d** were obtained from 4-substituted cyclopent-4-ene-1,3-diones **3a-d** (Scheme 1). The diones **3a-d** were synthesized in high yields by Jones oxidation of 2-substituted 4-hydroxycyclopent-2-enone derivatives **4**, which are widely used as prostaglandin precursors.[8] 4-Methylcyclopent-4-ene-1,3-dione **3e** was obtained from 4-hydroxy-3-methylcyclopent-2-enone **5**. The diketones - 4-alkoxycarbonylmethylcyclopent-4-ene-1,3-diones **3b,c** - appeared to be unstable and underwent a rapid regioselective enolization forming 4-alkoxycarbonylmethyliden-3-hydroxycyclopent-2-enone **1b,c**.

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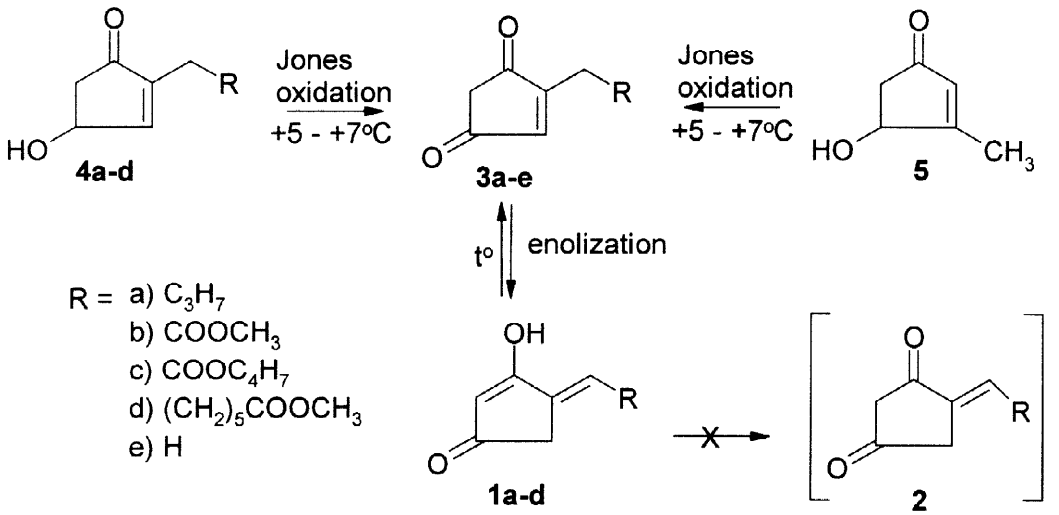
Scheme 1



The structure of the enols **1a-d** was established by the X-ray analysis of 4-butoxycarbonylmethyliden-3-hydroxycyclopent-2-enone **1c** and spectral data of **1a-d** (see experimental part). The X-ray structure showed an unexpected enolization of the ^3C carbonyl group and simultaneous migration of the endocyclic double bond into an exocyclic one (Fig.1).

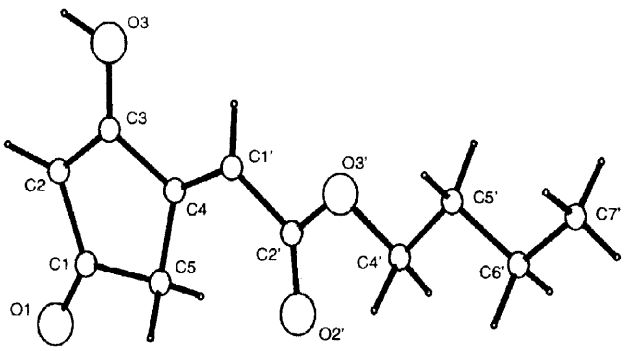


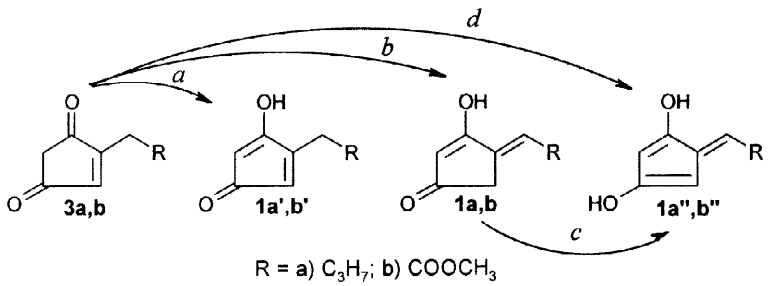
Figure 1: X-Ray structure of 4-butoxycarbonylmethyliden-3-hydroxycyclopent-2-enone **1c**.

In the literature we could not find completely proved precedent of the enolization of cyclopent-4-ene-1,3-diones. On the contrary, it is well documented, that the derivatives of cyclopent-4-ene-1,3-dione exist only in the diketonic form and are not able to enolize.[9] As described by De Puy,[9a-c] cyclopent-4-ene-1,3-dione, despite of its acidity, did not give ferric chloride test and keto-enol equilibrium favours the ketonic form, which was confirmed by IR and NMR spectra.[9c] IR spectra of substituted cyclopent-4-ene-1,3-diketones also did not show any presence of enolized molecules.[9f,g] In the enolic form they actually can be regarded as derivatives of highly reactive and metastable cyclopentadienone which could not be isolated from the reaction medium.[10] The

antiaromatic electronic structure of the cycle has been suggested to explain the lack of enolization of the cyclopent-4-ene-1,3-diones.[9]

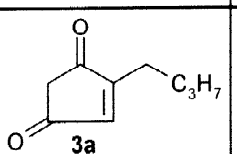
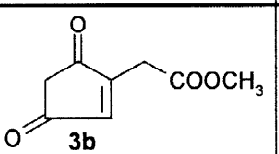
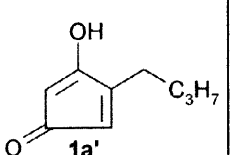
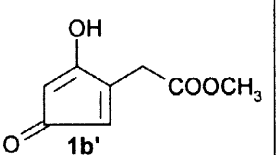
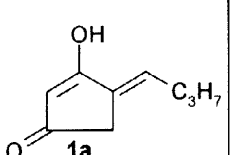
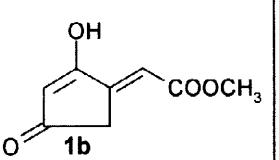
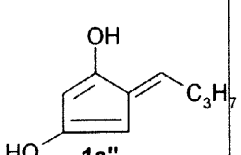
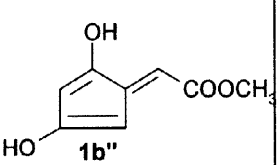
The contradiction between data given in literature[9] and enolization, observed for the enediones **3b,c** in our study, prompted us to evaluate the thermodynamic stability of the diketone **3b** and enol **1b**. The heats of formation obtained by MNDO calculations[11] of compounds **3a,b** (Table 1), were compared with those of possible enols **1a,b**, **1a',b'** and **1a",b"** and outlined in Scheme 2:

Scheme 2



enolization pathway	ΔΔH, Kcal R=C_3H_7	R=$COOCH_3$
a	11.29	7.75
b	**-0.53**	**-4.04**
c	8.99	10.39
d	8.46	6.35

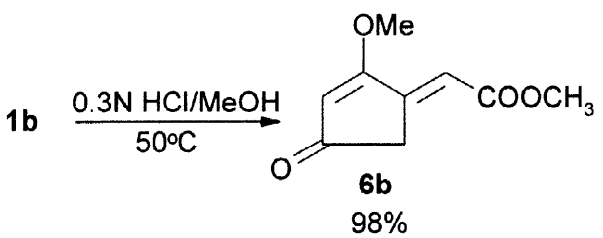
Table 1. Heat of Formation of the Diketones **3a,b** and their Enolization Products Calculated by MNDO Method.

Structure	Heat of formation, Kcal/mole	Structure	Heat of formation, Kcal/mole
 **3a**	**-68.31**	 **3b**	**-133.84**
 **1a'**	-57.02	 **1b'**	-126.09
 **1a**	**-68.84**	 **1b**	**-137.88**
 **1a"**	-59.85	 **1b"**	-127.49

The calculated heats of formation confirmed that the enols **1a,b** (pathway *b*) were the thermodynamically favourable structures ($\Delta\Delta H$ = -0.53 Kcal for **1a** and -4.04 Kcal for **1b**) and explained why the corresponding enolization products **1a',b'** with a cyclopentadienone ring fragment in the molecule (pathway *a*) and dienols **1a'',b''** (pathway *c*) could not be obtained. It is interesting to note that the enol **1a** is more stable only by 0.53 Kcal/mol than the diketone **3a**.

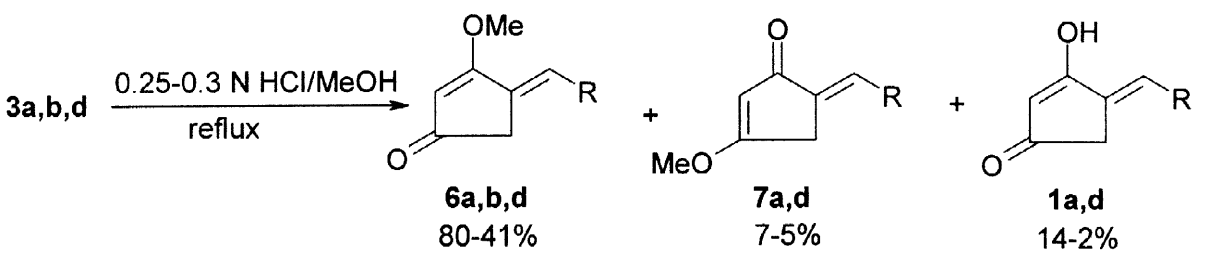
With this information to hand, we were motivated to investigate further the enolization of cyclopent-4-ene-1,3-diones **3a-e**, bearing CH_2R substituents at the ^{4}C-position. Enolization of the diketones **3a-e** with basic agents was successful only for the compound **3b,** while the compounds **3a** and **3d,e** decomposed by the treatment with bases. Enol-keto interconversion of **1b** afforded diketone **3b** in 30% yield by heating of the enol **1b** in DMFA at 120°C for 20 min; but the enol **1b** could not be isomerized into the parent diketone **2**. The subsequent treatment of enol **1b** with anhydrous HCl in methanol afforded enolether **6b** (Scheme3):

Scheme 3



It was established that diketones **3a,b,d** could be easily enolized in acidic media by refluxing with anhydrous HCl/MeOH for 4-5 h generating methyl ethers **6a,b,d** with high regioselectivity (Scheme 4):

Scheme 4



Enolization of the other carbonyl group was observed only for compounds **3a** and **3d** in a degree of 5-7% (isolated products). Structure of the enol ethers **6a,d** and **7a,d** was assigned on the basis of their ^{1}H NMR spectra by comparison of the methylene proton signals in the cycle for compounds **6a,d** and **7a,d**. Accordingly ,[12,13] signals of methylene protons in each of the isomeric enols appear at higher field, when these

protons are located at the α-position to the carbonyl group[a]. The significant differences were observed in UV spectra of enolethers **6a,d** and **7a,d** (Table 2). Enolethers **6a,d** showed absorption maxima at 210, 215 nm, 236-238 nm and 278 nm.

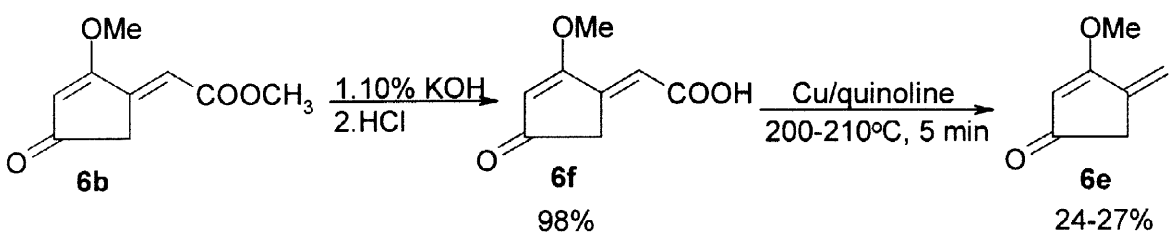
On the other hand, UV spectra of enolethers **7a** and **7d** showed only one absorption maximum at 262 nm and 254 nm, accordingly. This distinguishing feature of the enolethers **7a,d** is characteristic for some other alkylidenecyclopentenones, containing cross-conjugated dienone moiety,[14] and served as an additional evidence for an alternative enolization of ^{1}C carbonyl group of diketones **3a,d**.

Small amounts of enols **1a,d** (2-14%) were isolated as well. It is necessary to note that all isolated and purified enols and enolethers were stable and did not decompose by storage at the ambient temperature.

Attempts at either base or acid catalyzed enolization of 4-methylcyclopent-4-ene-1,3-dione **3d** failed. Compound **3d** decomposed on the treatment with basic reagents (NaOH, MeONa, triethylamine), but was stable in acidic media. Treatment of the diketone **3e** with 0.3 N HCl/MeOH at the boiling temperature for 3 days did not produce any traces of 4-methyliden-3-methoxycyclopent-2-enone **6e**. It was not clear whether compound **6e** was unstable and decomposed under reaction conditions or the energy of activation was remarkably higher than that for diketones **3a-d**.

The synthesis of enolether **6e** was solved *via* the decarboxylation of 4-carboxymethyliden-3-methoxycyclopent-2-enone **6f** as outlined in Scheme 5:

Scheme 5



Compound **6e** appeared to be stable and we attempted to enolize compound **3e** by heating the solution of diketone **3e** in anhydrous 1N HCl/MeOH in a hermetically closed Wheaton Vial at 80°C for 48 h. According to TLC and GC-MS analyses the reaction mixture contained unreacted diketone **3e** and 4-methylidene-3-methoxycyclopent-2-enone **6e**. The reversibility of the enolization was confirmed by heating the reaction product **6e** under the same conditions (Scheme 6).

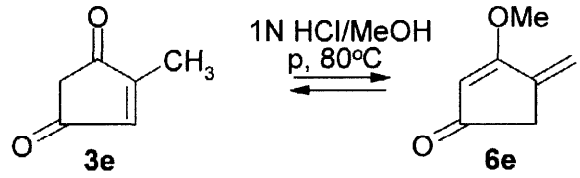
[a] **6a**: δ 2.96 (dd, 2H, J = 0.75 and 1.75 Hz, methylene CH_2), **7a**: δ 3.13 (s, 2H, methylene CH_2);**6d**: δ 2.91 (t, 2H, J = 1.0 Hz, methylene CH_2), **7d**: δ: 3.10 (s, 2H, methylene CH_2).

Table 2. UV Spectra of Diketones **3a,b,d,e**, Enols **1a,b,d** and Enolethers **5a,b,d-f, 6a,d**.

Compound	Solution [a]	λ_{max} (ε)		
Diketones	***A***	241 (11250)		
3a	***B***	241 (10670)		
	C	216 (7900), 223 (9090)	243 (5930)	295 (9880)
	A		231 (11820)	326 (1480)
3b	***B***		225 (19210)	290 (2590)
	C		231 (19210)	326 (9610)
	A		241 (11450)	
3d	***B***		241 (10970)	
	C	216 (9510), 223 (10480)	241 (6020)	294 (11840)
	A		237 (11680)	
3e	***B***		237 (12570)	
	C	212 (4960)	239 (8140)	263(6100), 300 (2120)
	C [b]	216 (4780)		265 (9730)
Enols	***A***	209 (9620), 216 (9310), 221 $(5890)_{shoulder}$		284 (13650)
1a	***B***	209 (9620), 215 $(8070)_{shoulder}$		280 (13650)
	C	209 $(8530)_{shoulder}$, 216 (10860)shoulder, 221(11790)	243 (4960)	292 (14740)
	A	224 $(13490)_{shoulder}$	231 (14640)	304 (9730)
1b	***B***	216 (13870), 219 $(13490)_{shoulder}$	243 (6940)	290 (1340)
	C		231 (20230)	320 (10790)
	A	217 $(20000)_{shoulder}$,		281 (19820)
1d	***B***	215 $(15000)_{shoulder}$,		278 (20220)
	C	217 $(17100)_{shoulder}$, 222(20360)	242 (10860)	293 (21720)
Enolethers [c]				
5a	***A***	211(11350), 215 (10320)	236 (3100)	278 (16470)
5b	***A***	216 (14780), 221 (14210)	245 (6530)	285 (15550)
5d	***A***	210(11070), 215(9900)	238 (4750)	278 (16020)
5e	***A***	205 (8930), 210 (8740)		268 (17670)
5f	***A***	216 (12730)	220 (12210)	282 (16160)
6a	***A***		262 (10660)	
6d	***A***		254 (15250)	

[a] Solution ***A*** - 60% MeOH, 40% H_2O; ***B*** - 60% MeOH, 40% 0.1N HCl; ***C*** - 60% MeOH, 40% 0.06N NaOH.
[b] The same solution after 3 days.
[c] There was not observed any difference in the UV spectra for solutions ***A***, ***B*** or ***C***.

Scheme 6



The ability of diketones **3a-e** to undergo an enolization was investigated by means of UV spectroscopy using three different solutions: ***A*** - neutral, consisting of 60% MeOH and 40% water, ***B*** - acidic, consisting of 60% MeOH and 40% 0.1N HCl and ***C*** - basic, consisting of 60% MeOH and 40% 0.06N NaOH. UV spectra of enols **1a,b,d** and enolethers **6a,b,d,e** and **7a,d** were measured in the same solutions. The results are summarised in Table 2.

In compliance with,[15] diketones **3a,d,e** showed only one absorption maximum characteristic for cyclopent-4-ene-1,3-diones in the solutions ***A*** and ***B***. Compound **3b** was prone to enolize even in neutral and acidic media.The UV spectra of **3b** and **1b** were almost identical in the solution ***C***.

Compounds **3a** and **3d** also showed the presence of the enol form in the basic medium but in a lower degree. Diketone **3e** slowly enolized in the solution ***C*** and in the UV spectrum in three days absorption maxima at 216 and 265 nm appeared, characteristic for the enolized molecule.

Unfortunately, we could not obtain and isolate 3-hydroxy-4-methylidencyclopent-2-enone **1e** in a preparative quantity.

In conclusion, we have established a novel and versatile procedure for the regioselective enolization of 4-substituted cyclopent-4-ene-1,3-diones **3a-d**. The present enolization provides a new and direct route to the 4-substituted derivatives of 3-hydroxy-4-cyclopentyliden-2-enones **1a-d** and their enolethers **6a-e**, which can be useful synthons for cyclopentanoid natural compounds.

ACKNOWLEDGEMENTS

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EXPERIMENTAL

General methods.

^{1}H NMR spectra were recorded at ambient temperature on WH-90/DS and WM-360 spectrometers in $CDCl_3$ using TMS as internal standard. Infrared spectra were recorded on a Perkin Elmer 580 B spectrometer. Mass spectra were recorded on a MS-50 (AEI) mass spectrometer at ionising potential 70 eV. Chromato-mass spectra were run on a

MS-25 (Kratos). All mass spectra are electron impact (E.I.) spectra. UV spectra were recorded on a Specord UV-Vis instrument. Elemental analyses were performed on a Carlo Erba EA 1108 instrument. Melting points were measured on a "Boetius"micro melting apparatus and uncorrected.

The X-ray structure analysis of the compound **1c** was performed by Θ/Θ scan with $\Theta_{max} = 25^{\circ}C$ using Syntex-$P2_1$ four-circle computer controlled single-crystal diffractometer with graphite monochromated Mo-K_α radiation. For X-ray measurements a well-shaped light yellow crystal was chosen. The unit cell constants were obtained from a least-squares refinement on the setting angles of 20 reflections. The monoclinic system crystal data were: a = 6.369(2), b = 10.326(1), c = 16.849(2) Å, $\beta = 90.71(2)^{\circ}$, V = 1108.0(4) $Å^3$, Z = 4, $d_{calcd} = 1.26\ g \times cm^{-3}$, space group P $2_1/c$. The structure was solved by a direct method using the program SHELXS-86.[16] The refinement of atomic positional and thermal anisotropic parameters of all non-hydrogen atoms was performed by full-matrix least squares procedure using SHELXL-93 program.[17] The position of hydrogen atoms were generated from assumed geometries and added (with isotopic temperature factors) to the set of atomic parameters and refinements.

SCF MNDO calculations of the studied systems were performed in valence approximation using s,p-basis of Slater's orbitals on Silicon Graphics computer. The geometrical parameters of the systems were obtained from X-ray diffraction data and used for calculations. The full optimisation of the parameters was performed by quantum chemical calculations[18] accordingly.

TLC analyses were performed on aluminium plates coated with Merck silica gel 60 F_{254} and visualised by UV light, 0.5% $KMnO_4$ solution and/or saturated 2,4-dinitrophenylhydrazine solution in 0.1 N HCl. Silica gel Silasorb 600 (LC) 30μm (Czechoslovakia) was employed for column chromatography. Mobile phase for TLC and preparative column chromatography were identical. Solvents were purified by routine techniques.

Jones' reagent was prepared by dissolving CrO_3 (6.68 g) in water (~12.5 mL) and concentrated H_2SO_4 (5.75 mL) at $20^{\circ}C$ and by adding water to the resulting mixture of the total volume 25.0 mL (1 mL solution contains 2.67 mmol CrO_3).

Anhydrous HCl solution in MeOH was prepared in a 25 mL measuring flask by dissolving a calculated amount of acetyl chloride in anhydrous methanol (~10 mL) at $0^{\circ}C$, the solution was allowed to warm to room temperature and methanol was added to a total volume of 25.0 mL.

Starting compounds.

4-Hydroxy-3-methylcyclopent-2-enone (5) was synthesized as reported.[19] **4-Hydroxy-2-butylcyclopent-2-enone (4a)** was obtained by the reported procedure.[20, 21] **2-Methoxycarbonylmethyl-4-hydroxycyclopent-2-enone (4b)** and **2-butoxycarbonylmethyl-4-hydroxycyclopent-2-enone (4c)** were prepared as previously described.[22] **2-(4-Methoxycarbonylhexyl)-4-hydroxycyclopent-2-enone (4d)** was prepared by a known procedure.[23, 24]

General procedure for the oxidation of 4-hydroxycyclopent-2-enone derivatives. A solution of 4-hydroxycyclopent-2-enone derivative **2a-e** (10 mmol) in acetone (20 mL) was cooled to $+3^{\circ}C$ and Jones' reagent (4.0 mL, 10.68 mmol) added dropwise. The reaction mixture was stirred at $+3 \div +7^{\circ}C$ for 30 min and isopropanol (5 mL) was added. After stirring for 1 h brine (10 mL) was added. The reactions product was extracted with benzene (2×20 mL), washed with brine (2×20 mL), dried over anhydrous Na_2SO_4, evaporated *in vacuo*, and purified by column

chromatography. **4-Butylcyclopent-4-ene-1,3-dione (3a)**, (94%), yellow oil: n_D^{20} 1.4915; TLC *Rf* 0.52 (benzene-diethyl ether, 9:1); IR (film): $1611_{\nu\ C=C}$; 1718, $1749_{\nu\ C=O}$; ^{1}H NMR 90 MHz, δ: 0.93 (m, 3H, $C^{1'}H_3$), 1.58 (m, 4H, $C^{2'}H_2$, $C^{3'}H_2$), 2.47 (m, 2H, $C^{4'}H_2$), 2.87 (s, 2H,C^2H_2), 6.84 (t, 1H, *J* = 1.5 Hz, C^5H); MS (*e/z*): 152(3, $M^{+\bullet}$), 137(3), 124(85), 110(99), 109(65), 94(40), 82(50), 81(100), 80(70), 68(75), 67(94), 53(70). Anal. Calcd. for $C_9H_{12}O_2$: C 71.03; H 7.95. Found: C 70.87; H 8.13. **4-Methoxycarbonylmethylcyclopent-4-ene-1,3-dione (3b)**, (91%), yellow oil: n_D^{20} 1.5314; TLC *Rf* 0.80 (benzene-acetone, 2:1) and *Rf* 0.48 (hexane-ethyl acetate, 1:1); IR (film):$1623_{\nu\ C=C}$; $1715_{\nu\ C=O}$; $1744_{\nu\ COOCH3}$; ^{1}H NMR 90 MHz, δ: 2.96 (s, 2H, C^2H_2), 3.60 (d, 2H, *J* = 1.5 Hz, $CH_{2\ methylene}$), 3.82 (s, 3H, $COOCH_3$), 7.29 (t, 1H, *J* = 1.5 Hz, C^5H); MS (*e/z*): 168(37, $M^{+\bullet}$), 140(16), 137(42), 124(26), 110(27), 96(73), 81(24), 67(100), 59(93), 54(52). Anal. Calcd. for $C_8H_8O_4$.: C 57.14; H 4.79. Found: C 57.02; H 4.86. **4-Butoxycarbonylmethylcyclopent-4-ene-1,3-dione (3c)**, (90.5%) yellow oil: n_D^{20} 1.4928; TLC *Rf* 0.70 (hexane-ethyl acetate, 2:1); IR (film): 1461, 1467, 1583, $1622_{\nu\ C=C}$; $1715_{\nu\ C=O}$; $1748_{\nu\ COOCH3}$. ^{1}H NMR 90 MHz, δ: 0.91(t, 3H, *J* = 7 Hz, CH_3), 1.13-1.69(m, 4H, CH_2CH_2), 2.89 (s, 2H, C^2H_2), 3.49 (d, 2H, *J* = 1.2 Hz, $CH_{2\ methylene}$), 4.09 (d, 2H, $COOCH_2$), 7.80 (t, 1H, *J* = 1.2 Hz, C^5H); MS (*e/z*): 210(6, $M^{+\bullet}$), 182(14), 164(17), 155(54), 137(100), 126(5), 110(75), 98(4), 82(19), 73(6), 67(61), 57(44), 51(5), 41(76), 39(58). Anal. Calcd. for $C_{11}H_{14}O_4$: C 62.85; H 6.71. Found: C 62.79; H 6.73. **4-(6-Methoxycarbonylhexyl)cyclopent-4-ene-1,3-dione (3d)**, (99%), white solid: m.p. 38.5-39°C (from diethyl ether at -50°C); TLC *Rf* 0.63 (hexane-ethyl acetate, 1:1) and *Rf* 0.91 (benzene-ethyl acetate, 1:2); IR (nujol):$1605_{\nu\ C=C}$; 1692, $1712_{\nu\ C=O}$; 1740, $1747_{\nu\ COOCH3}$; ^{1}H NMR 360 MHz, δ: 1.37 (m, 4H, $C^{4'}H_2$, $C^{3'}H_2$), 1.59 (m, 4H, $C^{2'}H_2$, $C^{5'}H_2$), 2.29 (t, 2H, *J* = 7.5 Hz, $C^{1'}H_2$), 2.87 (dt, 2H, *J* = 7.50 and 1.5 Hz, $C^{6'}H_2$), 2.87 (s, 2H, C^2H_2), 3.63 (s, 3H, $COOCH_3$), 6.89 (t, 1H, *J* = 1.5 Hz, C^5H); MS (*e/z*): 238(8, $M^{+\bullet}$), 207(21), 206(45), 188(8), 178(16), 162(13), 151(13), 152(13), 136(13), 135(13), 128(18), 123(21), 111(53), 110(100), 97(63), 87(18), 82(24), 81(24), 79(24), 74(37), 69(50), 67(47), 59(34), 55(47). Anal. Calcd. for $C_{13}H_{18}O_4$: C 65.53; H 7.61. Found: C 65.53; H 7.62. **4-Methylcyclopent-4-ene-1,3-dione (3e)**, (89%), yellow solid: m.p. 29-31°C; TLC *Rf* 0.48 (benzene-acetone, 9:1); [25] b.p.86-89°C/13 mm Hg ; UV, IS, ^{1}H NMR and Mass-Spectra are identical in many respects with the sample prepared by the known procedure.[26]

Enolization of 3b. To a stirred solution of diketone **3b** (0.79 g; 4.7 mmol) in dioxane (10 mL) a solution of DMAP (0.58 g; 4.7 mmol) in dioxane (5 mL) was added. The thick reaction mass was poured onto 50 g crushed ice and dissolved, then 2 mL of conc. HCl was added (pH~2), the solid reaction product was filtered, washed with cold water and dried to give **4-methoxycarbonylmethyliden-3-hydroxycyclopent-2-enone (1b)**: 0.50 g (63.6%), m.p. 141.5-143.5°C (from methanol); TLC *Rf* 0.28 (benzene-acetone, 2:1); IR (nujol):1560, 1645,$1655_{\nu\ C=C}$; $1710_{\nu\ C=O}$; 1720(shoulder),$1760_{\nu\ COOCH3}$; 2465, 2550, 2650, $2700_{\nu\ OH}$; ^{1}H NMR 90 MHz, δ: 3.33 (d, 2H, *J* = 1.75 Hz, C^5H_2), 3.77 (s, 3H, $COOCH_3$), 5.67 (s, 1H, C^2H), 6.29 (t, 1H, *J*= 1.75 Hz, $CH_{methylidene}$); MS (*e/z*): 168(57, $M^{+\bullet}$), 140(9), 137(53), 124(23), 110(10), 96(33), 81(11), 67(100), 59(80), 53(30). Anal. Calcd. for $C_8H_8O_4$: C 57.14; H 4.79. Found: C 57.09; H 4.72.

Enolization of 3c. The diketone **3c** enolized in **4-butyloxymethyliden-3-hydroxycyclopent-2-enone (1c)** by storage of the crude product for several weeks at ambient temperature without solvent. The solid enol was washed with benzene, diethyl ether and crystalls subjected to X-ray analysis; m.p.: 110-111°C (from dioxane); IR (nujol): 1465, 1495, 1572, $1645_{\nu\ C=C}$; $1715_{\nu\ C=O}$; $1748_{\nu\ COOCH3}$; 2360-2520, $2640_{\nu\ OH}$. ^{1}H NMR 90 MHz, δ: 0.87(t, 3H, *J* = 7 Hz, CH_3), 1.13-1.71(m, 4H, CH_2CH_2), 3.42 (d, 2H, *J* = 1.5 Hz, C^5H_2), 4.17 (t, 2H, *J* = 7 Hz, $COOCH_2$), 5.62 (s, 1H, C^2H), 6.40 (t, 1H,

J= 1.5 Hz, $CH_{methylidene}$), 11.71 (s, 1H, OH); MS (*e/z*): 210(3, $M^{+\bullet}$), 182(5), 164(4), 156(10), 155(25), 137(64), 126(5), 111(8), 110(45), 92(12), 67(81), 57(90), 41(100); Anal. Calcd. for $C_{11}H_{14}O_4$: C 62.85; H 6.71. Found: C 62.81; H 6.76.

Enolization of 3a,b,d in the presence of dry HCl/MeOH. A solution of diketone **3a,b,d** (1-3g) in 25 mL of 0.25 M anhydrous HCl/MeOH was refluxed for 5 h, concentrated *in vacuo*, the reaction products of **3a** and **3d** were dissolved in benzene (50 mL) and washed with brine (4×10 mL), dried over anhydrous Na_2SO_4, evaporated *in vacuo*, and the residue purified by column chromatography on silica gel with benzene-ethyl acetate, 1:1 as a mobile phase. Enolization of **3a** (1.1 g; 0.72 mmol), afforded unreacted diketone **3a** 0.31 g (28.2%), the less polar enol ether - **4-butylidene-3-methoxycyclopent-2-enone (6a)** 0.617 g (51%) - as a yellow oil at the ambient temperature, m.p. 14-16°C; n_D^{20} 1.5329; TLC *Rf* 0.46 (benzene, ethyl acetate,1:1); IR (film): 1574, 1610, 1690$_{\nu\ C=C}$; 1700, 1720(shoulder)$_{\nu\ C=O}$; ^{1}H NMR 90 MHz, δ: 0.93 (m, 3H, J= 7.5 Hz, $C^{1'}H_3$), 1.49 (m, 2H, J= 7.5 Hz, $C^{2'}H_2$), 2.13 (m, 2H, J= 7.5 Hz, $C^{3'}H_2$), 2.96 (dd, 2H, J= 0.75 and 1.75 Hz, C^5H_2), 3.89 (s, 3H, OCH_3), 5.44 (s, 1H, C^2H), 6.07 (dt, 1H, J= 7.5 and 1.5 Hz, $C^{4'}H$); MS (*e/z*): 166(13, $M^{+\bullet}$), 151(1), 137(8), 124(100), 109(21), 94(4), 77(10), 69(23), 66(13), 53(12). Anal. Calcd. for $C_{10}H_{14}O_2$: C 72.26; H 8.49. Found: C 70.36; H 8.42. The more polar enol ether - **5-butylidene-3-methoxy-cyclopent-2-enone (7a)** 0.080 g (6.7%) was isolated as an yellow oil; TLC *Rf* 0.34 (benzene-ethyl acetate, 1:1); IR (film): 1590, 1665$_{\nu\ C=C}$; 1704$_{\nu\ C=O}$; ^{1}H NMR 90 MHz, δ: 0.93 (m, 3H, J = 7.0 Hz, $C^{1'}$H3), 1.38 (m, 2H, J = 7.0 Hz, $C^{2'}H_2$), 2.11 (q, 2H, J = 7.0 Hz, $C^{3'}H_2$), 3.13 (s, 2H, C^5H_2), 3.73 (s, 3H, OCH_3), 5.44 (t, 1H, J = 0.75 Hz, C^2H), 6.51 (dt, 1H, J = 7.5 and 1.5 Hz, $C^{4'}H$); MS (*e/z*): 166(73, $M^{+\bullet}$), 142(100), 131(14), 129(27), 114(55), 111(27), 109(32), 95(18), 91(25), 79(25), 77(30), 69(80), 66(27), 55(27), 53(32). Anal. Calcd. for $C_{10}H_{14}O_2$: C 72.26; H 8.49. Found: C 71.78; H 8.71. **4-Butylyliden-3-hydroxycyclopent-2-enone (1a)** - 0.020g (2%), was isolated as yellow crystals: m.p. 122-125°C; TLC *Rf* 0.09 (benzene-ethyl acetate, 1:1); IR (nujol): 1560, 1625$_{\nu\ C=C}$; 1672$_{\nu\ C=O}$; 2350-2680$_{\nu\ OH}$; ^{1}H NMR 90 MHz, δ: 0.96 (t, 3H, J = 7.5 Hz, $C^{1'}H_3$), 1.49 (m, 2H, J = 7.5 Hz, $C^{2'}H_2$), 2.16 (q, 2H, J = 7.5 Hz, $C^{3'}H_2$), 3.33 (s, 2H, C^5H_2), 5.42 (s, 1H, C^2H), 6.24 (dt, 1H, J = 7.5 and 1.5 Hz, $C^{4'}H$), 11.60 (s, 1H, OH); MS (*e/z*): 152(23, $M^{+\bullet}$), 110(76), 95(35), 82(29), 69(23), 67(100), 53(35). Anal. Calcd. for $C_9H_{12}O_2$: C 71.03; H 7.95. Found: C 70.68; H 7.97. The diketone **3b** (2.82 g; 1.7 mmol) afforded 2.25 g (80.3%) of yellowish solid - **4-methoxycarbonylmethyliden-3-methoxycyclopent-2-enone (6b)**, which was filtered and washed with H_2O: m.p. 148-150°C (from benzene); TLC *Rf* 0.63 (benzene-acetone, 2:1) and *Rf* 0.22 (hexane-ethyl acetate, 1:1); IR (nujol): 1589, 1646, 1662$_{\nu\ C=C}$; 1695$_{\nu\ C=O}$; 1716$_{\nu\ COOCH3}$; ^{1}H NMR 90 MHz, δ: 3.42 (d, 2H, J = 1.75 Hz, C^5H_2), 3.78 (s, 3H, $COOCH_3$), 3.94 (s, 3H, OCH_3), 5.72 (s, 1H, C^2H), 6.29 (t, 1H, J = 1.75 Hz, $CH_{mehylidene}$); MS (*e/z*): 182(84, $M^{+\bullet}$), 167(30), 154(38), 151(25), 124(14), 123(28), 111(15), 92(12), 95(97), 80(28), 69(100), 59(30), 52(30). Anal. Calcd. for $C_9H_{10}O_4$: C 59.34; H 5.33. Found: C 59.46; H 5.38. Enolization of **3d** (1.0 g; 0.42 mmol) afforded unreacted diketone **3d** 0.196 g (19.6%), **4-(6-methoxycarbonylhexylidene)-3-methoxycyclopent-2-enone (6d)** 0.437 g (41.2%) as a white solid compound: m.p. 49-52°C (from dioxane); TLC *Rf* 0.43 (benzene-ethyl acetate, 1:1) and *Rf* 0.64 (benzene-ethyl acetate, 1:2); IR (nujol): 1572$_{\nu\ C=C}$; 1686$_{\nu\ C=O}$; 1742, 1750(shoulder)$_{\nu\ COOCH3}$; ^{1}H NMR 360 MHz, δ: 1.35 (m, 2H, $C^{3'}H_2$), 1.46 (m, 2H, $C^{4'}H_2$), 1.63 (m, 2H, J = 7.5 Hz, $C^{2'}H_2$), 2.12 (q, 2H, J = 7.5 Hz, $C^{5'}H_2$), 2.29 (t, 2H, J = 7.5 Hz, $C^{1'}H_2$), 2.91 (t, 2H, J = 1.5 Hz, C^5H_2), 3.63 (s, 3H, $COOCH_3$), 3.84 (s, 3H, OCH_3), 5.39 (s, 1H, C^2H), 5.97 (dt, 1H, J = 7.5 and 1.5 Hz, $C^{6'}H$); MS (*e/z*): 252(20, $M^{+\bullet}$), 221(7), 193(7), 152(9), 151(71), 149(10), 138(18), 137(20), 124(100), 112(27), 109(31), 95(16), 91(8), 81(13), 79(18), 74(24), 69(31), 59(18), 55(22). Anal. Calcd. for $C_{14}H_{20}O_4$: C 66.64, H 7.99. Found: C 66.65; H 7.96.The other enol ether **5-(6-methoxycarbonylhexylidene)-3-methoxycyclopent-2-enone**

(**7c**) 0.053 g (5.0%) was isolated as white crystals: m.p. 60-63°C; TLC *Rf* 0.32 (benzene-ethyl acetate, 1:1) and *Rf* 0.56 (benzene-ethyl acetate, 1:2); IR (nujol): 1590, $1650_{\nu\ C=C}$; $1692_{\nu\ C=O}$; 1747, 1765(shoulder)$_{\nu\ COOCH3}$; ^{1}H NMR 360 MHz, δ: 1.34 (m, 2H, $C^{3'}H_2$), 1.47 (m, 2H, *J* = 7.5 Hz, $C^{4'}H_2$), 1.62 (m, 2H, *J* = 7.5 Hz, $C^{2'}H_2$), 2.14 (q, 2H, *J* = 7.5 Hz, $C^{5'}H_2$), 2.28 (t, 2H, *J* = 7.5 Hz, $C^{1'}H_2$), 3.10 (s, 2H, C^4H_2), 3.63 (s, 3H, $COOCH_3$), 3.83 (s, 3H, OCH_3), 5.42 (t, 1H, *J* = 1.5 Hz, C^2H), 6.44 (dt, 1H, *J* = 7.5 and 1.5 Hz, $C^{6'}H$); MS (*e/z*): 252(28, $M^{+\bullet}$), 221(8), 220(10), 193(8), 192(11), 179(3), 177(4), 165(5), 152(18), 151(100), 139(17), 138(38), 125(18), 123(14), 112(37), 109(12), 91(12), 77(12), 69(18), 59(10), 55(12). Anal. Calcd. for $C_{14}H_{20}O_4$: C 66.64, H 7.99. Found: C 66.28; H 8.01. The yellow crystals of **4-(6-methoxycarbonylhexylidene)-3-hydroxycyclopent-2-enone (1d)** - 0.143 g (14.3%): m.p. 116-117°C (from dioxane); TLC *Rf* 0.38 (benzene-ethyl acetate, 1:2); IR (nujol): 1555, 1620, $1635_{\nu\ C=C}$; $1671_{\nu\ C=O}$; $1735_{\nu\ COOCH3}$; 2420-2550, $2700_{\nu\ OH}$; ^{1}H NMR 360 MHz, δ: 1.38 (m, 2H, $C^{3'}H_2$), 1.50 (m, 2H, *J* = 7.5 Hz,$C^{4'}H_2$), 1.65 (m, 2H, *J* = 7.5 Hz, $C^{2'}H_2$), 2.18 (q, 2H, *J* = 7.5 Hz, $C^{5'}H_2$), 2.32 (t, 2H, *J* = 7.5 Hz, $C^{1'}H_2$), 3.01 (d, 2H, *J* = 1.5 Hz, C^5H_2), 3.67 (s, 3H, $COOCH_3$), 5.41 (s, 1H, C^2H), 6.32 (dt, 1H, *J* = 7.5 and 1.5 Hz, $C^{6'}H$); MS (*e/z*): 238(10, $M^{+\bullet}$), 207(35), 206(42), 188(8), 178(22), 162(13), 151(15), 137(27), 136(25), 135(25), 129(20), 123(23), 111(63), 110(100), 97(68), 82(28), 81(38), 79(42), 74(35), 69(57), 67(57), 59(30), 55(62). Anal. Calcd. for $C_{13}H_{18}O_4$: C 65.53; H 7.61. Found: C 65.54; H 7.63.

Saponification of 6b. To the 4-methoxycarbonylmethyliden-3-methoxycyclopent-2-enone **(6b)** (0.557g; 3 mmol) 15 mL of 10% KOH solution was added and stirred for 30 min at ambient temperature, then 5 mL of conc. HCl (pH~2) was added, stirred for 30 min and extracted with ethyl acetate (5×20 mL), dried over anhydrous Na_2SO_4, evaporated *in vacuo* to give 0.474 g (89%) of crude **4-carboxymethyliden-3-methoxycyclopent-2-enone (6f)** as a white solid: m.p. 233-234°C (from dioxane); TLC *Rf* 0.35 (benzene-acetone, 2:1); IR (nujol): 1580, 1650, $1670_{\nu\ C=C}$; $1720_{\nu\ C=O}$; 1750(shoulder)$_{\nu\ COOH}$; ^{1}H NMR 90 MHz, δ: 3.44 (d, 2H, *J* = 1.75 Hz, C^5H_2), 3.93 (s, 3H, OCH_3), 5.73 (s, 1H, C^2H), 6.27 (t, 1H, *J* = 1.75 Hz, $CH_{methylidene}$); MS (*e/z*): 168(42, $M^{+\bullet}$), 124(74), 110(16), 97(13), 95(39), 81(10), 80(10), 69(100), 67(19), 55(23). Anal. Calcd. for $C_8H_8O_4$: C 57.14; H 4.79. Found: C 56.96; H 4.78.

Decarboxylation of 6f. A mixture of 4-carboxymethyliden-3-methoxycyclopent-2-enone **(6f)** (0.14 g; 0.83 mmol), copper dust (0.14 g), hydroquinone (8 mg) and destilled quinoline (0.6 mL, ~5 mmol) was heated at 185-205°C under argon for 20 min, cooled, diluted with 10 mL of benzene and acidified with 0.6 mL of conc. HCl. The aqueous layer was separated and organic solution washed with brine (2×5 mL) (pH~7), dried over anhydrous Na_2SO_4, concentrated *in vacuo* (~1 mL) and purified by column chromatography affording **4-methylidene-3-methoxycyclopent-2-enone (6e)** 0.025 g (24%) as yellow crystals: m.p. 34-35°C; TLC *Rf* 0.50 (petrol ether-dioxane, 4:1) and *Rf* 0.58 (benzene-acetone, 2:1); IR (film): 1575, 1675, $1690_{\nu\ C=C}$; $1725_{\nu\ C=O}$; ^{1}H NMR 90 MHz, δ: 3.05 (t, 2H, *J* = 1.75 Hz, C^5H_2), 3.91 (s, 3H, OCH_3), 5.27 (dd, 1H, *J* = 1.5 Hz, $CH_{methylidene}$), 5.54 (dd, 2H, *J* = 1.5 Hz, $CH_{methylidene}$), 5.64 (t, 1H, *J* = 1.75 Hz, C^2H); MS (*e/z*): 124(100, $M^{+\bullet}$), 123(18), 109(4), 95(7), 81(5), 69(62), 66(75), 55(9), 53(13). Anal. Calcd. for $C_7H_8O_2$: C 67.72; H 6.50. Found: C 67.67; H 6.90.

Enolization of 3d. A mixture of 4-methylcyclopent-4-ene-1,3-dione **(3d)** (10 mg) and 1 mL of dry 1N HCl/MeOH was heated in the hermetically closed Wheaton Vial® at 80°C for 48 h. According to TLC and GC-MS analysis the reactions mixture contained **4-methylidene-3-methoxycyclopent-2-enone (6e)** and unreacted **diketone (3d)**.

Heating of 6b. A mixture of 4-methoxycarbonylmethyliden-3-hydroxycyclopent-2-enone **(6b)** (0.168 g; 1 mmol), 1 mL of dry dimethylformamide and 10 μL H_2O was heated at 120°C for 20 min, then cooled and diluted with 10 mL of benzene, filtered through a 1 cm layer of silica gel, evaporated and purified by column chromatography (eluent benzene-ethyl acetate, 9:1) afforded 0.050 g (30%) of diketone **3b**, (assigned by ^{1}H NMR spectra).

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