Tetrahedron Vol. 40, No. 6, pp. 1051 to 1060, 1984
Printed in Great Britain.

0040-4020/84 $3.00 + .00
Pergamon Press Ltd.

PHASE-TRANSFER CATALYSIS—3[1]

ACETYLATION OF 2-ACYLCYCLOALKANONES

R. ALAN JONES* and MALCOLM J. STOKES
School of Chemical Sciences, University of East Anglia, Norwich, NR4 7TJ, England

(*Received in the UK 5 June* 1983)

Abstract—With the exception of 2-formylcyclohexanone, which yields the *E-exo*-enol acetate, the phase-transfer catalysed acetylation of 2-acylcyclohexanones produces the 1-acetoxycyclohexene derivatives as the major products. The 1-acetoxy derivative is also obtained in good yield from the acetylation of 2-methoxycarbonylcyclopentanone but, generally, acetylation of 2-acylcyclopentanones yields the *E-exo*-enol acetates. 2-Acetylcyclopentanone, however, produces not only the *E*- and *Z-exo*-enol acetates, but also the *endo*-enol acetate, in a ratio of *ca* 2:2:1. The *exo* and *endo*-enol acetates were distinguished by ^{13}C NMR spectroscopy and use of LIS reagents confirmed the configurational assignments of the *exo*-isomers.

In contrast to the phase-transfer catalysed alkylation of 1,3-dicarbonyl compounds in which the formation of the C-monoalkylated products is the predominant reaction,[2] the acylation of acyclic 1,3-dicarbonyl compounds under similar reaction conditions has been shown to yield the O-acylated derivatives.[3] Both the *E*- and *Z*-enol esters are produced but, unlike the analogous reaction conducted in the presence of alkali metal cations which stabilises through chelation the *Z,Z*-enolate anion (**2**) and thereby promotes the predominant formation of the *Z*-enol esters (**5**), the phase-transfer catalysed reactions generally favour the formation of the *E*-enol esters (**6**) via the intermediate formation of the more stable "free" *Z*, *E*- and *E,E*-enolate anions (**3**) and (**4**).

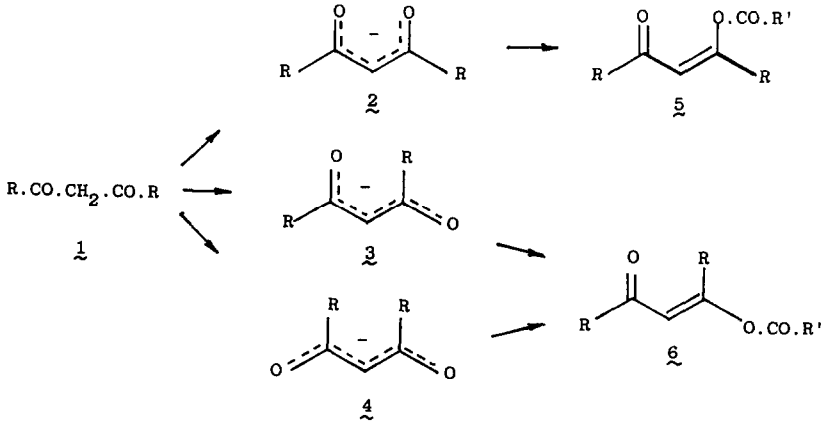
As the initial studies were conducted on symmetrical acyclic 1,3-diketones, it was of interest to examine the acylation of 2-acylcycloalkanones where O-acylation could lead not only to configurational isomers (**10**) and (**11**), analogous to (**5**) and (**6**), but also to two different site isomers (**10**) and (**11**) or (**12**). It was hoped that, if the reaction pathways were sufficiently specific, the phase-transfer catalysed acylation reaction could be used for the selective protection of one of the carbonyl groups. Further, we wished to determine whether the factors which control the *exo*- and *endo*-enol ratios of the acylcycloalkanones (**7**⇌**9**), would influence the differential formation of the isomeric enol esters (**10–12**).

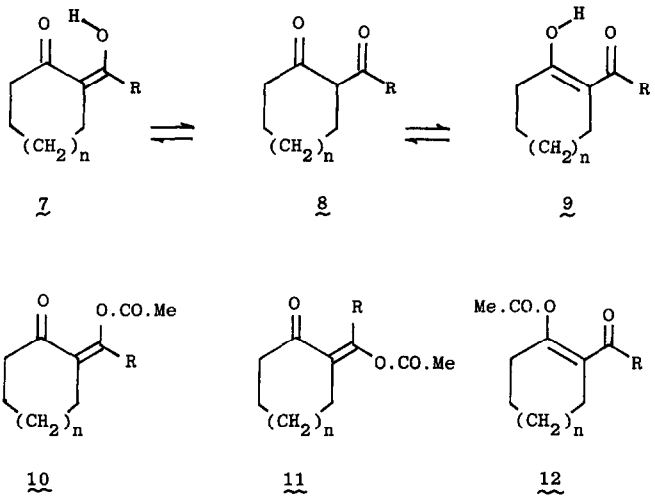
The relative stabilities of the two enol forms (**7**) and (**9**) are strongly influenced by the ring size and it is usually accepted that the *exo*-enol (**7**) is more stable than the *endo*-enol (**9**) for the 5-membered ring systems and *vice versa* for the 6-membered ring systems. This generalisation[4] is based upon a consideration of "ring strain", but steric factors,[5] and torsional and angle bending strains[6] can cause deviations from the expected behaviour.

The predominant tautomeric forms of the majority of the β-dicarbonyl compounds used in this investigation are well established, but there has been some controversy regarding the position of the tautomeric equilibrium for 2-formylcyclohexanone.[7] Our comparative ^{13}C NMR studies described below indicate that the *endo*-enol structure (**9**, n = 1, R = H) is the predomonant tautomeric form.

RESULTS AND DISCUSSION

The phase-transfer catalysed acetylation of 2-formyl-, 2-acetyl-, 2-benzoyl- and 2-methoxycar-





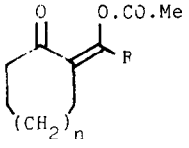
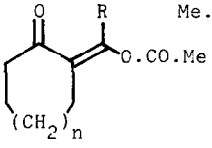
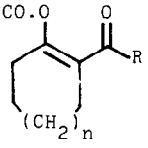
7 8 9

10 11 12

bonylcyclopentanones and the corresponding cyclohexanones was examined under reaction conditions similar to those described previously[3] using tetra-n-butylammonium hydrogen sulphate as the catalyst. The only products isolated from all of the reactions resulted from O-acetylation (Table 1). The major products from the acetylation of acylcyclopentanones were the *exo*-enol acetates but, in contrast with the *Z*-configuration of the enols (**7**, n = 0), which are stabilised by intramolecular H-bonding, the enol acetates had the *E*-configuration (**11**, n = 0). This is analogous to the previously observed predominance of the *E*-enol acetates obtained from the acetylation of acyclic 1,3-diketones, as discussed above, and would be particularly favoured in the acetylation of 2-formylcyclopentanone, where the *E-exo*-enol acetate would be sterically less crowded than the *Z*-isomer. It is significant, however, that the *E-exo*- and the *Z-exo*-enol acetates (**10** and **11**, n = 0, R = Me) were obtained in approximately equal amounts from the acetylation of 2-acetylcyclopentanone, together with the *endo*-enol acetate. It is probable that both steric and electronic factors are important in the control of these reactions. Predictably, acetylation of 2-methoxycarbonylcyclopentanone produced only the *endo*-enol acetate.

The results of the acetylation of the 2-acylcyclohexanones are more remarkable than those from the corresponding cyclopentanones. Not unexpectedly, although the yield of the acetylated

Table 1. Phase-transfer catalysed acetylation of 2-acylcycloalkanones

					Recovered Starting Material
n = 0	R = H	a	90%	a	6%
n = 0	R = Me	b	b	b	—
n = 0	R = Ph	c	95%	c	—
n = 0	R = OMe	—	—	74%	26%
n = 1	R = H	d	67%	d	13%
n = 1	R = Me	—	—	90.5%	9.5%
n = 1	R = Ph	—	—	95.5%	4.5%
n = 1	R = OMe	—	—	61%	39%

a two other isomers (2% and 2%) also detected by GC/MS.

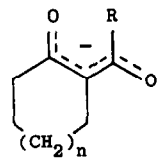
b the three isomers (overall yield 86%) could not be isolated in a pure form. The approximate exo-Z : exo-E : endo ratio was 2:2:1.

c one other isomer (5%) was also detected by GC/MS.

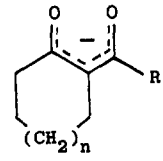
d two other isomers (11 and 9%) were also detected by GC/MS.

product is considerably less than those from other acetylation reactions, 2-methoxycarbonylcyclohexanone gave the *endo*-enol acetate (**12**, n = 1, R = OMe) and 2 acetylcyclohexanone, which exists predominantly in the *endo*-enol form, was also converted in high yield into the *endo*-enol acetate (**12**, n = 1, R = Me). In contrast, 2-formylcyclohexanone, which also exists in the *endo*-enol form, produced the *E-exo*-enol acetate (**11**, n = 1, R = H), as the major acetylated derivative (67%), together with smaller yields of two other isomers. A similar observation has been reported for the reaction of 2-formylcyclohexanone with methyl isocyanate.[8] The preferential formation of the *E-exo*-enol acetates results from the greater stability of the "free" *Z*, *E*-enolate anion (**13**, n = 1, R = H), compared with the *Z*,*Z*-isomeric anion (**14**) (*cf* acylation of acylic β-dicarbonyl compounds) and in the absence of intramolecular H-bonds, which enhance the stabilisation of the "strain free" *endo*-enol structure (**9**, n = 1, R = H), the sterically more favourable *E-exo*-enol acetate (**11**, n = 1, R = H) is produced from (**13**). On the basis of "ring strain" one might expect the thermodynamically more stable *endo*-enol acetate to be formed, but it is apparent that acetylation of the "formyl" oxygen atom of the resonance stabilised anions is kinetically the more favourable reaction pathway. The formation of the *Z-exo*-enol ether from the methylation of 2-formylcyclohexanone with diazomethane[9] can also be explained in terms of the preferential reaction at the "formyl" oxygen atom, but in this instance the diazomethane is reacting with rapidly equilibrating *endo*- and *Z-exo*-enol structures to yield an ion pair of the enolate anion and the methyl carbenium ion, which results in the retention of the *Z*-configuration for the *exo*-enol ether. Thermal intramolecular migration of the acetyl group to give the *endo*-enol acetate was not observed (*cf* Ref. 10).

The acetylation of 2-acetylcyclohexanone and of



13



14

2-benzoylcyclohexanone, produced the *endo*-enol acetate (**12**, n = 1, R = Me or Ph) in high yield. The reaction of the benzoyl derivative, which exists predominantly in the diketo form,[5] was somewhat unexpected, but it was also observed that acetylation of 1-phenylbutan-1,3-dione, the predominant tautomeric form of which is *Z*-1-hydroxy-1-phenylbut-1-en-3-one, yields *E*-3-acetoxy-1-phenylbut-2-en-1-one, as the major product (80%). Predictably, methyl 3-oxo-3-phenylpropanoate only produces methyl *E*-3-acetoxy-3-phenylpropenoate under similar conditions.

Attempted identification of the structures of the enol acetates by ^{1}H NMR spectroscopy led to many ambiguities, but a comparative study of the ^{13}C NMR spectral data for the 2-acylcycloalkanones and the their O-acetylated derivatives permitted the structural assignments for the products given in Table 1 to be made. With the exception of 2-formylcyclohexanone, the preferred tautomeric forms of the acylcycloalkanones were well established and the structures were confirmed by the ^{13}C NMR chemical shifts given in Tables 2 and 3. Where the dicarbonyl structures were also present in significant amounts in equilibrium with the enol ketones, signals for both tautomeric forms were recorded. Thus, for example, the dicarbonyl form and the *Z-exo*-enol form of 2-acetylcyclopentanone were observed, although we obtained no evidence for the *endo*-enol form (*cf* Ref. 11). The *endo*-enol structure for 2-formylcyclohexa-

Table 2. ^{13}C Chemical shifts for 2-acylcylclopentanones and their O-acetylated derivatives

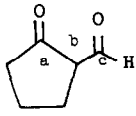
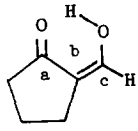
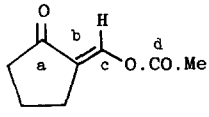
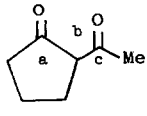
	"a"	"b"	"c"	"d"
	212.7	62.4	196.9	—
	210.4	113.2	159.5	—
	207.8	121.5	139.3	167.3
	212.8	62.7	205.1	—

Table 2. (*Contd*)

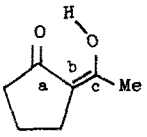
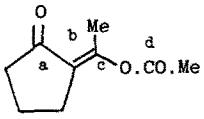
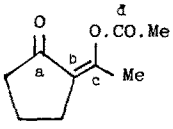
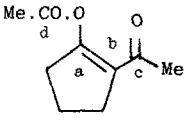
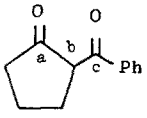
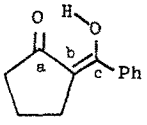
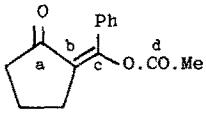
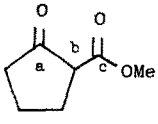
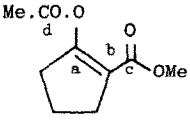
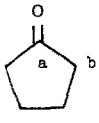
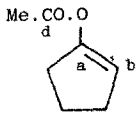
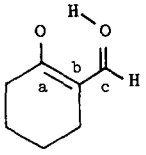
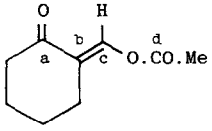
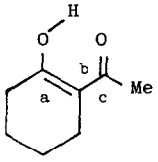
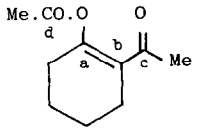
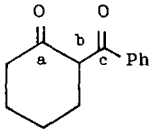
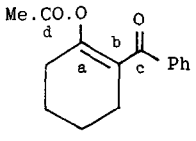
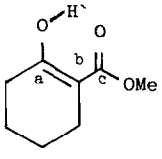
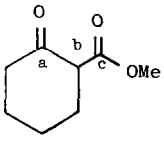
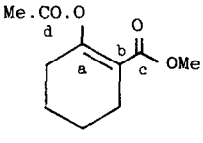
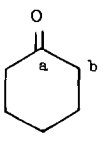
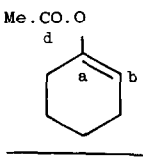
	"a"	"b"	"c"	"d"
	202.4	109.9	175.7	—
	206.7	124.6	155.0	167.3
	203.1	123.0	149.9	168.2
	159.2	126.5	194.5	167.1
	213.2	57.1	195.6	—
	210.4	109.2	168.5	—
	204.6	123.9	148.2	168.6
	212.2	54.6	169.8	—
	159.9	118.0	164.0	167.7
	220.4	38.3	—	—
	151.1	112.8	—	168.4

Table 3. ^{13}C Chemical shifts for 2-acylcyclohexanones and their O-acetylated derivatives

	"a"	"b"	"c"	"d"
	187.5	108.9	184.8	—
	200.9	121.4	141.4	167.0
	182.1	107.0	198.9	—
	154.0	125.9	198.3	168.4
	208.5	58.8	197.4	—
	150.1	125.1	197.1	168.3
	173.1	97.6	170.4	—
	206.0	57.2	172.1	—
	156.1	117.4	166.0	168.7
	212.0	42.0	—	—
	148.5	113.8	—	169.1

none was established by a comparative study of the ^{13}C NMR chemical shifts of C-1, C-2 and the exocyclic "carbonyl" group (atoms "a", "b" and "c" in Tables 2 and 3). The average difference in the chemical shifts of the signals for atoms "a", "b" and "c" for 5- and 6-membered rings bearing identical substituents and having the same preferred tautomeric forms ($\Delta\delta_{5\to6}$) were -5.2, $+0.6$ and $+2.4$ ppm, respectively. From these data, a predicted set of chemical shift values for the *Z-exo*-enol form of 2-formylcyclohexanone can be obtained (Table 4), using the *Z-exo*-enol form of 2-formylcyclopentanone as the model system. Similarly, average relative chemical shift differences for atoms "a", "b" and "c" for cycloalkanones bearing formyl or acetyl groups and having the same tautomeric structure ($\Delta\delta_{COMe\to CHO}$) were, respectively *ca* $+3.0$, -0.1 and -14.0 ppm. Using these data and the *endo*-enol from of 2-acetylcyclohexanone as the model system, it was possible to estimate the expected chemical shifts for the *endo*-enol form of 2-formylcyclohexanone. The predicted chemical shifts for the dicarbonyl tautomeric form was calculated from the averaged values of $\Delta\delta_{CO_2Me\to COMe}$ and using the dicarbonyl form of 2-methoxycarbonylcyclohexanone as the model system. Comparison of the calculated data with the observed data for 2-formylcyclohexanone clearly shows that the *endo*-enol structure is the more important tautomeric form.

During the course of this work, a comparative study of the ^{13}C NMR spectra of the "cis"-enols of 1,3-diketones and the corresponding enol ethers provided evidence for the unsymmetrical character of the H-bonded –OH $\cdots$ O=C bridge and permitted the tautomeric preference of the *exo*- and *enol*-structures (**7**) and (**9**) to be made.[10] Based upon the reasonable assumption that the effect of methylation is similar for both the 5- and 6-membered ring compounds and, using the data reported for the *exo*-enol ethers of the 2-formylcycloalkanones, together with chemical shift data for the *Z-exo*-enol form of 2-formylcyclopentanone, the calculated chemical shifts for the signals for atoms "a" and "c" of the *Z-exo*-enol form of 2-formylcyclohexanone are 202.7 and 162.4 ppm, thereby confirming further that the *exo*-enol structure is not the predominant tautomer.

The chemical shift data for the O-acetylated derivatives, presented in Tables 2 and 3, are self-consistant (see also Table 5) and, wherever a possible ambiguity arose, the signals have been unequivocally identified by measurement of the C–H coupling constants. Additionally, comparison of the data from lanthanide shift ^1H and ^{13}C spectra of the enol acetates derived from 2-formylcyclohexanone and 2-acetylcyclohexanone clearly established the *E-exo*-enol acetate structure for the former compound and the *endo*-enol acetate structure for the latter compound and eliminated all other possible structures.[12] With these derivatives and the *endo*-enol acetates derived from the 2-methoxycarbonylcycloalkanones as model compounds, the structures assigned for the other enol acetates were confirmed.

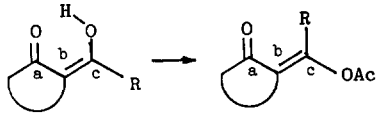
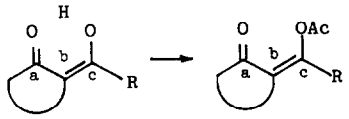
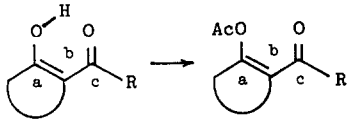
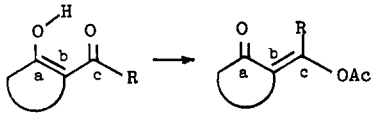
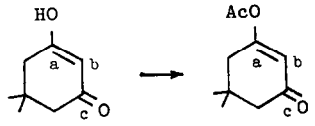
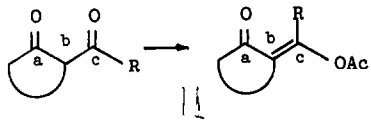
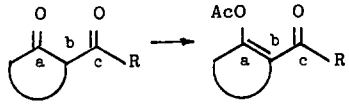
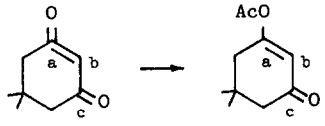
It is noteworthy from the data presented in Table 5 that O-acetylation of the tautomeric systems not only produced the expected large downfield shift of the C-2 signal for the dicarbonyl structures, as a result of the change in the hybridisation from sp^3 to sp^2 (Table 5, entries 6–9), but also caused a downfield shift of *ca* 13 ppm of the C-2 signal for the enolic tautomers (**7** and **9**) upon the formation of the *exo*-enol acetates and a corresponding downfield shift of *ca* 19 ppm, as a result of O-acetylation of the *endo*-enol system. More significantly, the signal for the enolic C atom, i.e. atom "a" of the *endo*-enol system (**9**) and atom "c" of the *exo*-enol system (**7**), experienced an upfield shift of *ca* 20 ppm upon formation of the corresponding enol acetates, compared with the smaller upfield shift 2–3 ppm observed upon acetylation of a saturated hydroxyl group.[13] In contrast, the shift of the signal for the non-enolised ketonic C atom upon formation of the enol acetates was almost insignificant ($+1$ to -4 ppm).

These changes in the ^{13}C chemical shifts upon the formation of the O-acetylated products are not only influenced by the fixation of the tautomeric equilibrium, but also reflect the release of the system from intramolecular H-bonding with a simultaneous change in the electron distribution within the enolic system, as a result of the acetylation. More specifically, removal of the intramolecular H-bond should reduce the polarisation of the carbonyl group with a concomitant small upfield shift of the ketonic signal. Acetylation of the polarised $\overset{\delta+}{H}-\overset{\delta-}{O}$ group also results in the formation of a cross-conjugated system with a concomitant reduction in the $+M$ effect and a simultaneous increase in the $-I$ effect of the enolic oxygen atom upon the α, β-unsaturated ketonic system. This effect would also produce upfield shifts of the signals for atoms "a" and "c", with the greater electronic effect resulting in the larger upfield shift being experienced by the =C–OAc group. This is apparent from the chemical shift data for the enolic form of dimedone and its O-acetylated derivative (Table 5, entry 5) where, in the absence of intramolecular H-bonding in the enol, O-acetylation produces upfield shifts of 24 and 4 ppm of the signals for the enolic and ketonic C atoms, respectively.

Table 4. Calculated and observed chemical shifts (ppm) for the tautomeric forms of 2-formylcyclohexanone

	"a"	"b"	"c"
diketo form (calc.)	202.5	65.1	190.8
Z-exo-enol form (calc.)	205.2	113.8	161.8
endo-enol form (calc.)	185.1	106.9	184.9
observed data	187.5	108.9	184.8

Table 5. Effect of acetylation upon the ^{13}C chemical shifts

		"a"	"b"	"c"
1.		upfield 4 ± 2 ppm	downfield 13 ± 5 ppm	upfield 20 ± 1 ppm
2.		downfield 1 ppm	downfield 13 ppm	upfield 26 ppm
3.		upfield 22 ± 5 ppm	downfield 19 ± 1 ppm	upfield 2 ± 2 ppm
4.		downfield 13 ppm	downfield 12 ppm	upfield 43 ppm
5.		upfield 24 ppm	downfield 13 ppm	upfield 4 ppm
6.		upfield 6 ± 2 ppm	downfield 63 ± 4 ppm	upfield 52 ± 6 ppm
7.		upfield 55 ± 3 ppm	downfield 65 ± 1 ppm	upfield 4 ± 3 ppm
8.		upfield 36 ppm	downfield 59 ppm	upfield 4 ppm
9.		upfield 76 ± 3 ppm	downfield 73 ± 2 ppm	

EXPERIMENTAL

IR spectra were recorded on a Perkin–Elmer 257 spectrometer. ^1H NMR spectra were measured, unless otherwise stated, in $CDCl_3$ at 60 MHz using a Perkin–Elmer R12 spectrometer or, at 100 MHz, using a Varian HA100 spectrometer. All ^{13}C NMR spectra were measured in $CDCl_3$ using a Jeol FX-100 spectrometer. Preparative thin-layer chromatographic separation of the acetylated products was carried out on Kieselgel HF_{254} using, unless otherwise stated, diethyl ether–petroleum ether (1:1) as the eluant. GC analysis of the acetylated compounds was conducted on a Perkin–Elmer F33 gas chromatograph at 110 or 120° using 10% SE-30 on Chromasorb (80–100 mesh). Mass spectral data were obtained using a combined Perkin–Elmer Sigma 3 gas chromatograph/Kratos MS25 mass spectrometer. High resolution mass spectra and accurate mass measurements were provided by the Food Research Institute Mass Spectrometry Unit, Norwich using an AEI MS902 spectrometer.

2-Formylcyclopentanone. Ethanol (5 ml) was added to a

stirred mixture of sodium (11.5 g, 0.5 mol), cyclopentanone (42 g, 0.5 mol) and ethyl formate (55 g, 0.743 mol) in toluene (1000 ml) at 0°. The mixture was stirred for 6 h at 0° and was then allowed to come to room temperature. A further volume of ethanol (150 ml) was added and the mixture was stirred for 1 h. The ethanol was removed under reduced pressure, water (200 ml) was added, and the organic layer was separated from the aqueous layer and washed with water (150 ml). The combined aqueous layers were acidified with hydrochloric acid (6M, 170 ml) and extracted with ether (2 × 100 ml). The combined ether extracts were washed with sat sodium chloride (50 ml) and dried ($MgSO_4$). Evaporation of the solvent under reduced pressure gave the crude diketone, which was recrystallised from petroleum ether to give a 2-formylcyclopentanone (1.2 g, 2%) m.p. 76° (lit[14] m.p. 76–77°). IR ν_{max} (Nujol) 1600 cm^{-1} (br); ^1H NMR δ 1.72 – 2.70 (m), 7.30 (s) and 9.74 ppm (s); ^{13}C NMR (dicarbonyl form) 21.7 (C3), 24.8 (C4), 38.7 (C5), 62.4 (C2), 196.9 (CHO) and 212.7 (C1); (*Z-exo*-enol form) 20.8 (C3), 23.0 (C4), 38.2 (C5), 113.2 (C2), 159.5 (=CHOH) and 210.4 ppm (C1).

2-Formylcyclohexanone. Using a procedure analogous to that described above for the synthesis of 2-formylcyclopentanone, cyclohexanone (48 g, 0.5 mol) was converted into 2-formylcyclohexanone (18.6 g, 30%), which was isolated as an oil b.p. 52–55° at 0.9 mm Hg (lit[15] b.p. 70–72° at 5 mm Hg). IR ν_{max} (film) 1710 and 1600 cm^{-1}; ^1H NMR δ 1.56–2.01 (4H, m), 2.20–2.61 (4H, m), 8.70 (1H, s) and 14.30 ppm (1H, s); ^{13}C NMR (*endo*-enol form) 21.3 (C3), 22.7 (C4), 23.2 (C5), 31.3 (C6), 108.9 (C2), 184.8 (=CHOH) and 187.5 ppm (C1).

2-Acetylcyclopentanone. Acetyl chloride (12.75 g, 0.162 mol) was added dropwise with stirring over a period of 20 min to N-(1-cyclopent-1-enyl)pyrrolidine (22.2 g, 0.159 mol) and triethylamine (14.54 g, 0.243 mol) in toluene (500 ml) under nitrogen. The reaction mixture was heated under reflux for 16h. The cooled mixture was filtered and acetic acid (12 ml), sodium acetate (6 g) and water (12 ml) was added to the filtrate and the mixture was heated under reflux for 1h. The organic layer was separated from the cooled mixture and washed successively with hydrochloric acid (3M, 100 ml) and sat aqueous sodium hydrogen carbonate (100 ml) and then dried ($MgSO_4$).

Evaporation of the solvent gave the crude diketone (10.66 g, 94% purity by GC) to which was added sat aqueous copper acetate (250 ml) at 80°. The copper chelate was collected and recrystallised from diethyl ether:dichloromethane and then suspended in diethyl ether (100 ml) to which sulphuric acid (20% w/v, 125 ml) was added and the mixture shaken until the chelate had decomposed. The ether layer was separated from the acid, dried ($MgSO_4$), and evaporated to give 2-acetylcyclopentanone (8.34 g 41%), b.p. 90–92° at 20 mm Hg (lit[16] b.p. 79–81° at 12 mm Hg). IR ν_{max} (film) 1715, 1660 and 1615 cm^{-1}; ^1H NMR δ 1.60–2.70 (m), 2.00 (s), 2.30 (s), 3.28–3.59 (m), and 15.78 ppm (s); ^{13}C NMR (dicarbonyl form) 20.3 (C3), 25.8 (C4), 30.2 (COMe), 38.8 (C5), 62.7 (C2), 205.1 (COMe) and 212.8 (C1); (*Z-exo*-enol form) 20.3 (C3), 20.7 (C4), 25.2 (COMe), 36.9 (C5), 109.9 (C2), 175.7 (COMe) and 202.4 ppm (C1).

2-Acetylcyclohexanone. Using the procedure described above for the synthesis of 2-acetylcyclopentanone, N-(1-cyclohex-1-enyl)pyrrolidine (24.64 g, 0.162 mol) was converted into the crude diketone (17.55 g, 78% purity by GC), which was purified via the copper chelate to give 2-acetylcyclohexanone (12-3 g, 54%), b.p. 111–113° at 18 mm Hg (lit[17] b.p. 106–108° at 14 mm Hg). IR ν_{max} (film) 1710 and 1605 cm^{-1}; ^1H NMR δ 1.51–1.91 (4H, m), 2.11 (3H, s), 2.11–2.56 (4H, m) and 15.78 ppm (1H, s); ^{13}C NMR (*endo*-enol form) 21.7 (C3), 22.9 (C4), 24.4 (COMe), 24.9 (C5), 31.2 (C6), 107.0 (C2), 182.1 (C1) and 198.9 ppm (COMe).

2-Benzoylcyclopentanone. Using a procedure similar to that described for the acetylation of cyclopentanone, N-(1-cyclopent-1-enyl)pyrrolidine (44.95 g, 0.32 mol) was allowed to react with benzoyl chloride (23.04 g, 0.164 mol) to give 2-benzoylcyclopentanone (10.72 g, 34.8%), b.p. 104–106° at 1 mm Hg (lit[18] b.p. 132° at 2 mm Hg). IR ν_{max} (film) 1740 and 1620 cm^{-1}; ^1H NMR δ 1.73–3.03 (m), 7.34–8.13 (m) and 14.56 ppm (s); ^{13}C NMR (dicarbonyl form) 21.1 (C3), 27.2 (C4), 39.9 (C5), 57.1 (C2), 128.5 (phenyl C3, 5), 129.3 (phenyl C2, 6), 133.3 (phenyl C4), 140.6 (phenyl C1), 195.6 (COPh), and 213.2 (C1); (*Z-exo*-enol form) 21.3 (C3), 28.4 (C4), 37.6 (C5), 109.2 (C2), 128.1 (phenyl C3, 5), 128.3 (phenyl C2, 6), 130.9(phenyl C4), 134.5 (phenyl C1), 168.5(C=(OH)Ph) and 210.4 ppm (C1).

2-Benzoylcyclohexanone. Using a procedure analogous to that employed in the synthesis of 2-acetylcyclohexanone, N-(1-cyclohex-1-enyl)pyrrolidine (25 g, 0.166 mol) and benzoyl chloride (23.7 g, 0.166 mol) gave 2-benzoylcyclohexanone (17.45 g, 52.2%), as an oil, b.p. 112–113° at 0.3 mm Hg, which solidified to give white needles (from diethyl ether–dichloromethane), m.p. 86–88° (lit[19] m.p. 88–89°). IR ν_{max} 1740 and 1629 cm^{-1}; ^1H NMR δ 1.50–2.60 (8H, m), 4.18 (1H, t), 7.20–7.48 (3H, m) and 7.68–7.86 ppm (2H, m); ^{13}C NMR (dicarbonyl form) 23.1(C3), 27.3(C4), 30.0(C5), 58.8 (C2), 58.8 (C6), 128.5 (phenyl C3, 5), 128.6 (phenyl C2, 6), 133.2 (phenyl C4), 136.5 (phenyl C1), 197.4 (COPh) and 208.5 ppm (C1).

2-Methoxycarbonylcyclopentanone. Methyl chloroformate (16.64 g, 0.176 mol) was added to N-(1-cyclopent-1-enyl)pyrrolidine (42.24) g, 0.345 mol) in toluene (500 ml) under nitrogen with rapid stirring. The reaction mixture was heated under reflux for 6h, cooled and filtered. Acetic acid (12 ml), sodium acetate (6 g) and water (12 ml) were added to the reaction mixture and the mixture was heated under reflux for 1h. The organic layer was separated from the cooled mixture, washed with hydrochloric acid (3M, 100 ml) and dried ($MgSO_4$). Evaporation of the solvent gave the crude ester (16.34 g, 97% purity by GC), which was purified via its copper chelate, as described above for the acetyl derivatives, to give 2-methoxycarbonylcyclopentanone (10.7 g, 43%), b.p. 103° at 13 mm Hg (lit[19] 93–95° at 11 mm Hg). IR ν_{max} (film) 1755 and 1725 cm^{-1}; ^1H NMR δ 1.80–2.60 (6H, m), 3.00–3.53 (1H, m) and 3.73 ppm (3H, s); ^{13}C NMR (dicarbonyl form) 21.0 (C3), 27.4 (C4), 38.1 (C5), 52.4 (CO_2Me), 54.6 (C2), 169.8 (CO_2Me) and 212.2 ppm (C1).

2-Methoxycarbonylcyclohexanone. Using a procedure analogous to that described for the synthesis of the corresponding cyclopentanone derivative N-(1-cyclohex-1-enyl)pyrrolidine (53 g, 0.354 mol) and methyl chloroformate (16.64 g, 0.176 mol) gave the crude ester (18.84 g, 93% purity by GC), which was purified via its copper chelate to give 2-methoxycarbonylcyclohexanone (13.45 g, 49%), b.p. 110–112° at 21 mm Hg (lit[20] 94–95° at 10 mm Hg). IR ν_{max} (film) 1750, 1715, 1660 and 1615 cm^{-1}; ^1H NMR δ 1.50–1.90 (m), 2.10–2.45 (m), 3.73 (s) and 12.16 ppm (s); ^{13}C NMR (dicarbonyl form) 22.4 (C3), 27.1 (C4), 29.1 (C5), 41.5 (C6), 51.3 (CO_2Me), 57.2 (C2), 172.1 (CO_2Me) and 206.0 (C1); (*endo*-enol form) 22.0 (C3), 23.4 (C4), 29.1 (C5), 30.0 (C6), 52.1 (CO_2Me), 97.6 (C2), 170.4 (CO_2Me) and 173.1 ppm (C1).

General procedure for phase-transfer catalysed acetylation Reactions. The β-dicarbonyl compound (0.01 mol) in dichloromethane (25 ml) was added with stirring to tetra-n-butylammonium hydrogen sulphate (0.01 mol) in aqueous sodium hydroxide (2M, 10 ml) at room temp. Acetyl chloride (0.79 g, 0.01 mol) was added dropwise to the vigorously stirred mixture over a period of *ca* 2 min. Stirring was continued for a further hour and the two layers were then separated and the aqueous layer was extracted with dichloromethane (2 × 10 ml). The combined organic phases were washed with water (7 × 20 ml), dried ($MgSO_4$), filtered and the solvent removed under reduced pressure to yield the acetylated products.

2-(E-Acetoxymethylene)cyclopentanone. 2-Formylcyclopentanone (1.12 g, 0.01 mol) gave a liquid (1.24 g), which

was shown by GC/MS to contain starting material (5.9%), 2-(*E*-acetoxymethylene)cyclopentanone (89.9%), and two unidentified isomers (2.0% and 2.3%). An analytically pure sample of the major component, R_f 0.66, was obtained by preparative TLC (Found: C, 62.2; H, 6.9 $C_8H_{10}O_3$ requires C, 62.3; H, 6.5%.) ^{1}H NMR δ 1.83–2.05 (2H, m), 2.14 (3H, s), 2.37–2.40 (2H, m). 2.79 (2H, m) and 8.05 (1H, t); ^{13}C NMR 20.0 (C3), 20.7 (O.CO.Me), 25.5 (C4), 39.2 (C5), 121.5 (C2), 139.3 (=CH.OAc), 167.3 (O.CO.Me) and 207.8 ppm (C1).

Acetylation of 2-*acetylcyclopentanone*. 2-Acetylcyclopentanone (1.26 g, 0.01 mol) gave a liquid (1.44 g), which showed only one component by GC analysis, but comprised three components, as shown by TLC, which were identified by ^{13}C NMR spectroscopy as 2-(*Z*-1-acetoxyethylidine) cyclopentanone, 2-(*E*-1-acetoxyethylidine)cyclopentanone and 1-acetoxy-2-acetylcyclopent-1-ene in an approximate ratio of 2:2:1. For the mixture of components; found: C, 63.4; H, 7.2; $[M^+] = 168.0782$ $C_9H_{12}O_3$ requires C, 64.3; H, 7.2% $[M^+] = 168.0787$; IR ν_{max} (film) 1760 and 1720 cm^{-1}; ^{1}H NMR (CCl_4) δ 1.80–2.10 (m, ring CH_2), 2.27 (s, O.CO.Me) and 2.55–2.85 ppm (m, ring CH_2); for the individual compounds: ^{13}C NMR 2-(*Z*-1-acetoxyethylidene) cyclopentanone 19.1 (C3), 19.7 (=C(Me)OAc), 20.8 (O.CO.Me), 27.8 (C4), 39.8 (C5), 123.0 (C2), 149.9 (=C(Me)OAc), 168.2 (O.CO.Me) and 203.1 (C1), 2-(*E*-acetoxyethylidene)cyclopentanone, 17.0 (=C(Me)OAc), 19.6 (C3), 20.3 (O.CO.Me), 27.4 (C4), 40.4 (C5), 124.6 (C2), 155.0 (=C(Me)OAc), 167.3 (O. CO.Me) and 206.7 (C1), 1-acetoxy-2-acetylcyclopent-1-ene, 19.6 (C3), 21.0 (O.CO.Me), 28.8 (C4), 29.7 (COMe), 33.5 (C5), 126.5 (C2), 159.2 (C1), 167.1 (O.CO.Me) and 194.5 ppm (COMe).

2-(E-1-*Acetoxybenzylidine*)*cyclopentanone*. 2-Benzoylcyclopentanone (1.88 g, 0.01 mol) gave a liquid (2.10 g), which was shown by GC/MS to contain 2-(*E*-1-acetoxybenzylidene)cyclopentanone (95.3%) and an unidentified isomer (4.7%). An analytically pure sample of the major component, R_f 0.39, was obtained by preparative TLC Found: C, 71.3; H, 6.1 $[M^+] = 230.0947$; $C_{14}H_{14}O_3$ requires C, 73.0; H, 6.1%, $[M^+] = 230.0943$. IR ν_{max} (film) 1755, 1700 and 1600 cm^{-1}; ^{1}H NMR δ 1.54–2.31 (3H, m), 2.36 (3H, s), 2.54–3.14 (3H, m) and 7.31–7.80 ppm (5H, m); ^{13}C NMR 20.9 (C3), 20.5 (O.CO.Me), 30.4 (C4), 39.5 (C5), 123.9 (C2), 128.1 (phenyl C3, 5), 128.3 (phenyl C2, 6), 130.1 (phenyl C4), 134.5 (phenyl C1), 148.2 (=C(Ph)OAc), 168.6 (O.CO.Me) and 204.6 ppm (Cl).

1-*Acetoxy*-2-*methoxycarbonylcyclopent*-1-*ene*. 2-Methoxycarbonylcyclopentanone (1.42 g, 0.01 mol) gave a liquid (1.73 g), which was shown by GC/MS to contain starting material (26.2%) and 1-acetoxy-2-methoxycarbonylcyclopent-1-ene (73.8%). An analytically pure sample was obtained by preparative TLC. Found: C, 58.7; H, 6.9 $C_9H_{12}O_4$ requires C, 58.7; H, 6.6%. IR ν_{max} (film) 1775, 1670 and 1660 cm^{-1}; ^{1}H NMR δ 1.73–2.08 (2H, m), 2.16 (3H, s), 2.44–2.70 (4H, m), and 3.64 ppm (3H, s) ^{13}C NMR 19.1 (C3), 20.9 (O.CO.Me), 29.4 (C4), 33.5 (C5), 51.3 (CO_2Me), 117.0 (C2), 159.9 (C1), 164.0 (CO_2Me) and 167.7 ppm (O.CO.Me).

2-(E-*Acetoxymethylene*)*cyclohexanone*. 2-Formylcyclohexanone (1.26 g, 0.01 mol) gave a liquid (1.62 g), which was shown by GC/MS to contain starting material (12.9%), 2-(*E*-acetoxymethylene)cyclohexanone (67.1%) and two unidentified isomers (10.7% and 9.3%). An analytically pure sample of the major product, R_f 0.48, was obtained by preparative thin-layer chromatography. Found: C, 62.1; H, 7.5; $[M^+] = 168.0776$ $C_9H_{12}O_3$ requires C, 64.3; H, 7.1%; $[M^+] = 168.0793$. IR ν_{max} (film) 1770, 1690 and 1615 cm^{-1}; ^{1}H NMR δ 1.41–2.02 (4H, m), 2.09 (3H, s), 2.09–2.73 (4H, m) and 8.08 ppm (1H, t); ^{13}C NMR 20.7 (O.CO.Me), 22.7 (C3), 23.2 (C4), 24.3 (C5), 40.3 (C6), 121.4 (C2), 141.4 (=CH.OAc), 167.0 (O.CO.Me) and 200.6 ppm(C1).

1-*Acetoxy*-2-*acetylcyclohex*-1-*ene*. 2-Acetylcyclohexanone (1.40 g, 0.01 mol) gave a liquid (1.75 g), which was shown by GC/MS to contain starting material (9.5%) and 1-acetoxy-2-acetylcyclohex-1-ene (90.5%). An analytically pure sample, R_f 0.45, was obtained by preparative TLC Found: C, 65.7; H, 8.0 $C_{10}H_{14}O_3$ requires C, 65.9, H, 7.7%. IR ν_{max} (film) 1760 and 1715 cm^{-1}; ^{1}H NMR (CCl_4) δ 1.56–1.94 (4H, m), 1.94–2.54 (4H, m), 2.17 (3H, s) and 2.21 ppm (3H, s); ^{13}C NMR 21.3 (O. CO.Me), 21.8 (C3), 22.3 (C4), 25.0 (C5), 28.9 (C6) 30.5 (COMe), 125.9 (C2), 154.9 (C1), 168.4 (O.CO.Me) and 198.3 ppm (CO.Me).

1-*Acetoxy*-2-*benzoylcyclohex*-1-*ene*. 2-Benzoylcyclohexanone (2.02 g, 0.01 mol) gave a liquid (2.40 g), which was shown by GC/MS to contain starting material (4.5%) and 1-acetoxy-2-benzoylcyclohex-1-ene (95.5%). An analytically pure sample of the product R_f 0.80, was obtained by preparative TLC. Found: C, 72.6; H, 6.6; $[M^+] = 244.1083$ $C_{15}H_{16}O_3$ requires C, 73.8; H, 6.6%; $[M^+] = 244.1100$. IR ν_{max} (film) 1815, 1760, 1710 and 1650 cm^{-1}; ^{1}H NMR δ 1.48 (3H, s), 1.60–2.00 (3H, m), 2.22–2.57 (5H, m), 7.28–7.56 (3H, m) and 7.60–7.82 ppm (2H, m); ^{13}C NMR 20.2 (O.CO.Me), 21.7 (C3), 22.4 (C4), 26.1 (C5), 27.5 (C6), 125.1 (C2), 128.3 (phenyl C3, 5), 128.6 (phenyl C2, 6), 132.6 (phenyl C4), 137.8 (phenyl C1), 150.1 (C1), 168.3 (O. CO.Me) and 197.1 ppm (COPh).

1-*Acetoxy*-2-*methoxycarbonylcyclohex*-1-*ene*. 2-Methoxycarbonylcyclohexanone (1.56 g, 0.01 mol) gave a liquid (1.28 g), which was shown by GC/MS to contain starting material (39.0%) and 1-acetoxy-2-methoxycarbonylcyclohex-1-ene (61.0%). An analytically pure sample of the product was obtained by preparative TLC. Found: C, 60.2; H, 7.1 $C_{10}H_{14}O_4$ requires C, 60.6; H, 7.1%. IR ν_{max} (film) 1745, 1670 and 1605 cm^{-1}; ^{1}H NMR δ 1.51–1.75 (4H, m), 2.13–2.36 (4H, m), 2.13 (3H, s) and 2.20 ppm (3H, s); ^{13}C NMR 21.3 (O. CO. Me), 22.1 (C3), 22.8 (C4), 29.2 (C5), 29.8 (C6), 50.4 (CO_2Me), 117.4 (C2), 156.1 (C1), 166.0 (CO_2Me) and 168.7 ppm (O.CO.Me).

E-3-*Acetoxy*-1-*phenylbut*-2-*en*-1-*one*. 1-Phenylbutan-1,3-dione (1.62 g, 0.01 mol) gave a liquid (2.0 g), which was shown by GC/MS to contain starting material (10.3%), an unidentified acetylated product (9.5%) and *E*-3-acetoxy-1-phenylbut-2-en-1-one (80.2%). An analytically pure sample of the major component, R_f 0.46, was obtained by preparative TLC. Found: C, 70.6; H, 6.2 $C_{12}H_{12}O_3$ requires C, 70.6; H, 5.9%. IR ν_{max} (film) 1765, 1675 and 1620 cm^{-1}; ^{1}H NMR (CCl_4) δ 2.12 (3H, s), 2.32 (3H, s), 6.65 (1H, s), 7.20–7.46 (3H, m) and 7.70–7.90 ppm (2H, m); ^{13}C NMR 18.9 (C4), 21.4 (O.CO.Me), 113.5 (C2), 128.1 (phenyl C3, 5), 128.5 (phenyl C2, 6), 132.8 (phenyl C4), 138.6 (phenyl C1), 163.6 (C3), 168.0 (O.CO. Me) and 190 ppm (C1).

Ethyl E-3-*Acetoxy*-3-*phenylpropenoate*. Ethyl benzoylacetate (1.92 g, 0.01 mol) gave a liquid (2.25 g), which was shown by GC/MS to contain starting material (13.4%), an unidentified acetylated product (11.9%) and ethyl *E*-3-acetoxy-3-phenylpropenoate (74.7%). An analytically pure sample of the major product was obtained by preparative TLC using ethyl acetate–hexane (15:85) as the eluant. Found: C. 67.0; H, 6.0 $C_{13}H_{14}O$ requires C, 66.7; H, 6.0%. IR ν_{max} (film) 1740, 1685, 1640 and 1620 cm^{-1}; ^{1}H NMR (CCl_4) δ 1.24 (3H, s), 2.27 (3H, s), 4.12 (2H, q), 6.12 (1H, s) and 7.21–7.69 ppm (5H, m); ^{13}C NMR 14.2 (CO_2CH_2Me), 21.0 (O.CO.Me), 60.3 (CO_2CH$_2$Me), 106.2 (C2), 125.9 (phenyl C3, 5), 128.8 (phenyl C2, 6), 130.9 (phenyl C4), 133.3 (phenyl C1), 157.9 (C3), 164.2 (C1) and 168.0 ppm (O.CO.Me).

1-*Acetoxycyclopent*-1-*ene*. Cyclopentanone (5.0 g, 0.06 mol), isopropenyl acetate (20.86 g, 0.21 mol), and a catalytic amount of toluene-p-sulphonic acid were refluxed for 15h at 85°. Excess isopropenyl acetate and the acetone formed during the reaction were removed under reduced pressure and the residue distilled to give 1-acetoxycyclopentene (6.3 g, 84%), b.p. 41–42° at 8 mm Hg. Found: C, 66.3; H, 7.85 $C_7H_{10}O_2$ requires C, 66.7; H, 8.0%. IR ν_{max} (film) 1750 and 1655 cm^{-1}; ^{1}H NMR (CCl_4) δ 1.80–2.08 (2H, m), 2.00 (3H, s), 2.20–2.46 (4H, m) and 5.26 (1H, t); ^{13}C NMR 21.0 (O.CO.Me), 21.2 (C3), 28.8 (C4), 31.1 (C5), 112.8 (C2), 151.8 (C1) and 168.4 ppm (O.CO.Me).

1-Acetoxycyclohex-1-ene. In a manner similar to that used for the synthesis of 1-acetoxycyclopent-1-ene, cyclohexanone was converted into 1-acetoxycyclohex-1-ene (82.2%), b.p. 60–61° at 6 mm Hg. Found: C, 68.9; H, 8.8 $C_8H_{12}O_2$ requires C, 68.6; H, 8.6%. IR ν_{max} (film) 1750 and 1690 cm^{-1}; ^1H NMR δ 1.40–1.80 (4H, m), 1.90–2.20 ((4H, m), 1.96 (3H, s) and 5.16 ppm (1H, t); ^{13}C NMR 2.0 (O.CO.Me), 21.9 (C3), 22.8 (4), 23.7 (C), 27.0 (C6), 113.8 (C2), 148.5 (C1), and 169.1 ppm (O.ÇO.Me).

1-Acetoxy-5,5-dimethylcyclohex-1-en-3-one. Acetylation of 5,5-dimethylcyclohexa-1,3-dione (5 g, 0.036 mol) with isopropenyl acetate (12.6 g, 0.126 mol) and a catalytic amount of toluene-p-sulphonic acid gave 1-acetoxy-5,5-dimethylcyclohex-1-en-3-one (5.15 g, 79%), b.p. 128–129° at 8 mm Hg. Found: C, 65.4; H, 8.0 $C_{10}H_{14}O_3$ requires C, 65.95; H, 7.7%. IR ν_{max} (film) 1770 and 1670 cm^{-1}; ^1H NMR δ 1.10 (6H, s), 2.21 (3H, s), 2.26 (2H, s), 2.43 (2H, s) and 5.92 ppm (1H, s); ^{13}C NMR 21.2 (O.CO.Me), 28.1 (CMe_2), 33.1 (C5), 42.2 (C4), 50.8 (C6), 116.5 (C2), 167.4 (C1), 167.9 (O.ÇO.Me) and 199.3 ppm (C3).

REFERENCES

[1]Part 2. S. S. Badesha and R. A. Jones, *Synth. Commun.* **11**, 557 (1981).

[2]Eg A. Brandstrom and U. Junggren, *Acta Chem. Scand.* **23**, 3585 (1969); **25**, 1469 (1971); *Tetrahedron Letters.* 473 (1972).

[3]R. A. Jones, S. Nokkeo and S. Singh, *Synth. Commun.* **7**, 195 (1977).

[4]H. C. Brown, H. J. Brewster and H. Schechter, *J. Am. Chem. Soc.* **76**, 467 (1954); H. C. Brown, *J. Org. Chem.* **22**, 439 (1957).

[5]R. D. Campbell and H. M. Gilow, *J. Am. Chem. Soc.* **84**, 1440 (1962).

[6]E. W. Garbish, Jr., *J. Am. Chem. Soc.* **87**, 505 (1965).

[7a]E. W. Garbish, Jr., *J. Am. Chem. Soc.* **85**, 1696 (1963); [b]I. Deutsch and K. Deutsch, *Tetrahedron Letters.* 1849, (1966); [c]M. Gorodetsky, A. Luz and Y. Mazur, *J. Am. Chem. Soc.* **89**, 1183 (1967).

[8]W. R. Benson, B. Kagon, E. Lustig, J. T. Chen and J. Shulman, *J. Org. Chem.* **32**, 3635 (1967).

[9]J. C. J. Barna and M. J. T. Robinson, *Tetrahedron Letters.* 1455 (1979).

[10]E. Wachsen and K. Hartke, *Chem. Ber.* **108**, 138 (1975); **108**, 683 (1975); **109**, 1353 (1976); *Liebigs Ann. Chem.* 730 (1976).

[11]G. A. Olah, J. L. Grant and P. W. Westerman, *J. Org. Chem.* **40** 2102 (1975).

[12]M. J. Stokes, Ph.D. Thesis, University of East Anglia (1981).

[13]Data taken from E. Breitmaier, G. Hass and W. Voelter, *Atlas of Carbon-13 NMR Data.* Heyden, London (1979).

[14]W. S. Johnson and W. E. Shelberg, *J. Am. Chem. Soc.* **67**, 1745 (1945).

[15]C. Ainsworth, *Organic Synthesis*, Coll. Vol. 4, p. 536. Wiley, New York (1963).

[16]B. Eistert and R. Wessendorf, *Chem. Ber.* **94**, 2590 (1961).

[17]G. Vavon and J-M. Conia, *Compt. Rend.* **233**, 876 (1951).

[18]R. D. Campbell and W. L. Harmer, *J. Org. Chem.* **28**, 379 (1963).

[19]C. R. Hauser, B. I. Ringler, F. W. Suramer and D. F. Thompson, *J. Am. Chem. Soc.* **69**, 2649 (1947).

[20]R. Levine and C. R. Hauser, *J. Am. Chem. Soc.* **66**, 1768 (1944).