Studies in Vilsmeier Chemistry, V[1)]

Vilsmeier Reactions of 2-Alkyl-2-cyclohexen-1-ones: A Novel Route to Dihydrobenzaldehydes, the Formation of Allyl Alcohols as By-products, and the X-ray Crystallographic Structure of 3-Chloro-2-methyl-2-cyclohexen-1-ol

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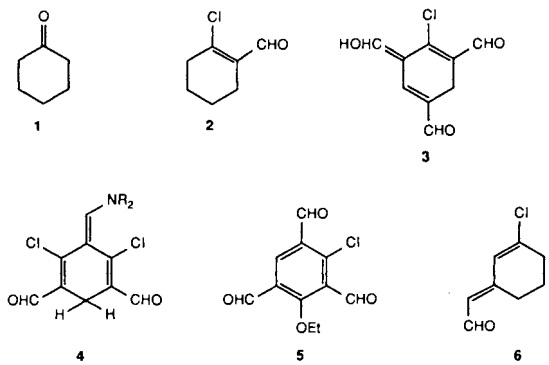
A series of 2-alkyl-2-cyclohexen-1-ones on reaction with 4-formylmorpholine in the presence of $POCl_3$ gave the corresponding 3-alkyl-2-chloro-5,6-dihydrobenzaldehydes, usually accompanied by significant amounts of allylic alcohols as by-products. The structure of the allylic alcohol 12a from 2-methyl-2-cyclohexen-1-one was confirmed by X-ray analysis. The allylic alcohols are probably formed by addition of oxyanions to Vilsmeier intermediates.

Vilsmeier-Reaktionen, V. – Vilsmeier-Reaktionen von 2-Alkyl-2-cyclohexen-1-onen: Ein neuer Zugang zu Dihydrobenzaldehyden, Bildung von Allylalkoholen als Nebenprodukte sowie Röntgenstrukturanalyse von 3-Chlor-2-methyl-2-cyclohexen-1-ol

Die Umsetzung einer Reihe von 2-Alkyl-2-cyclohexen-1-onen mit 4-Formylmorpholin in Gegenwart von $POCl_3$ lieferte die entsprechenden 3-Alkyl-2-chlor-5,6-dihydrobenzaldehyde, meistens begleitet von erheblichen Mengen an Allylalkoholen als Nebenprodukte. Die Struktur des Allylalkohols **12a** aus 2-Methyl-2-cyclohexen-1-on wurde durch Röntgenstrukturanalyse bestimmt. Die Allylalkohole entstehen vermutlich durch Addition von Oxyanionen an Vilsmeier-Zwischenprodukte.

Vilsmeier reagents convert unsubstituted saturated cycloalkanones into β-chlorovinyl aldehydes, e.g. cyclohexanone (**1**) into **2**[2,3)]. Considerable work has also been carried out in our laboratory recently on the reactions of unsaturated analogs of 2-cyclohexen-1-one, and of its 3-substituted derivatives with Vilsmeier reagents[1)]. Surprisingly, reaction products of several distinct types were obtained depending on the 3-substituent: thus, 2-cyclohexen-1-one itself gives the enolic aldehyde **3**[1b)], readily oxidized to 1-chloro-2,4,6-triformylbenzene; 3-hydroxy-2-cyclohexen-1-one (cyclohexane-1,3-dione) forms the cross-conjugated triene **4**[1a,1d)], 3-ethoxy-2-cyclohexen-1-one produces 1-chloro-3-ethoxy-2,4,6-triformylbenzene (**5**)[1c)], whereas 3-methyl-2-cyclohexen-1-one undergoes formylation at the 3-methyl carbon atom to give **6**[1c)].



1 2 3 4 5 6

With such a diversity of products from 3-substituted 2-cyclohexen-1-ones, it seemed important to establish the sensitivity of the reaction course to substituent variation in 2-substituted 2-cyclohexen-1-ones. The sole example of this class examined in our previous work was 2-methyl-2-cyclohexen-1-one (**7a**); we reported[1c)] that it gave a mixture of 2-chloro-3-methyl-5,6-dihydrobenzaldehyde (**13a**) together with a chlorine-containing hydroxy compound, the structure of which was tentatively assigned as the allylic alcohol **12a**. We have now repeated this work, and extended it to a variety of other 2-alkyl-2-cyclohexen-1-ones (**7b–e**).

The starting ketones **7a–e** were prepared by the Birch reduction of *o*-methoxybenzoic acid followed by alkylation of the dianion according to the method of Taber[4)], or by chlorination and subsequent dehydrohalogenation in the case of 2-methyl-2-cyclohexen-1-one[5)]. These 2-alkyl-2-cyclohexen-1-ones (**7a–e**) on reaction with 4-formylmorpholine/$POCl_3$ at 25°C were all found to afford the corresponding β-chlorovinyl aldehydes **13a–e** (Table 1).

Characterization of the 2-chloro-1-formyl-1,3-cyclohexadienes: The structures of the β-chlorovinyl aldehydes **13a–e** were supported by their spectra. The ^{1}H-NMR spectrum (Table 2) for **13a** displayed resonances at δ 10.36 (s, 1H) and 6.23 (t, 1H, J = 4.0 Hz) which could be assigned to the aldehydic and vinylic protons, respectively. The 2-methyl protons were assigned to a singlet at δ 1.93 which integrated for three protons while the methylene protons of the cyclohexane ring displayed a multiplet integrating for four pro-

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Table 1. Reaction of 2-alkyl-2-cyclohexen-1-ones with 4-formylmorpholine/$POCl_3$ at 25°C

Ketone	R	Procedure Time [h]	Hyrolysis Reagent	Column Eluent	Aldehyde 13 Yield (%)	Form	High-Res. Found	Mass Spec. Calcd. (Formula)	Alcohol 12 Yield (%)	Form	High-Res. Found	Mass Spec. Calcd. (Formula)
7a	Me	2	Na_2CO_3	CH_2Cl_2	21[a,b]	oil	156.0341	156.0342 ($C_8H_9O^{35}Cl$)	33[b]	needles	[c]	–
7b	Et	4	Na_2CO_3	hexane/ benzene	36	oil	170.0499	170.0498 ($C_9H_{11}O^{35}Cl$)	12	oil	160.0654	160.0656 ($C_8H_{13}O^{35}Cl$)
7c	*n*-Pr	2.5	Na_2CO_3	benzene	23	oil	184.0649	184.0655 ($C_{10}H_{13}O^{35}Cl$)	3	oil	174.0811	174.0813 ($C_9H_{15}O^{35}Cl$)
7d	*i*-Pr	5	Na_2CO_3	benzene	15	oil	184.0659	184.0654 ($C_{10}H_{13}O^{35}Cl$)	5	oil	174.0811	174.0814 ($C_9H_{15}O^{35}Cl$)
7d	*i*-Pr	24	Na_2CO_3	benzene	24				0	–	–	–
7d	*i*-Pr	20	NaOH	benzene	20				0	–	–	–
7e	Allyl	2.5	Na_2CO_3	benzene	37	oil	182.0502	182.0498 ($C_{10}H_{11}O^{35}Cl$)	0	–	–	–

[a] NOE experiments confirmed structure **13a** and excluded the formation of 2-alkyl-1-chloro-4-formyl-1,3-cyclohexadienes. – [b] mp

Scheme 1

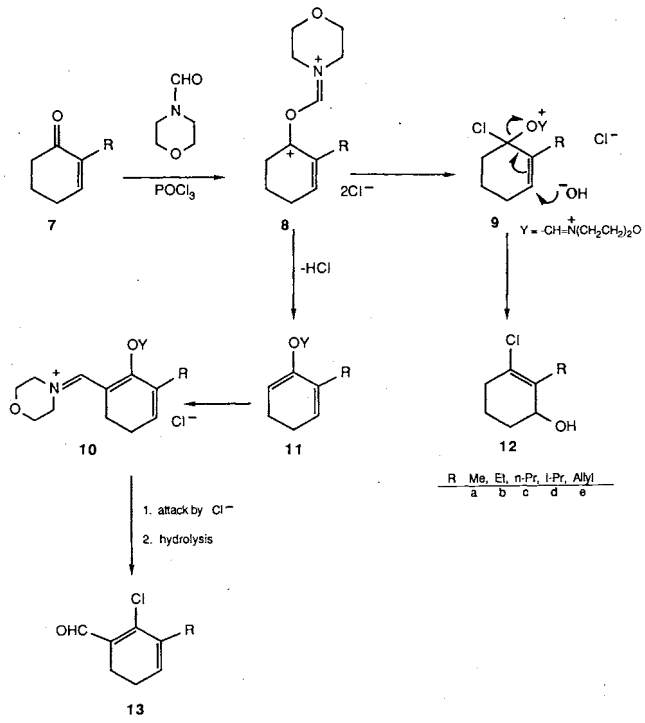


Table 2. ^{1}H- and ^{13}C-NMR chemical shifts (δ) for aldehydes **13a–e**[a]

^{1}H-NMR Data	CHO	=CH	(4H, m)	α-CH_2(2H)	γ-CH_3(3H)
13a	10.36	6.23	2.13–2.66	–	1.93 (s)
13b	10.30	6.33	2.00–2.88	2.00–2.88	1.14 (t, 7 Hz)
13c	10.10	6.20	1.16–2.69	1.16–2.69	0.90 (t, 6 Hz)
13d	10.13	6.28	2.00–2.60	2.66–3.27[b]	1.07 (d, 8 Hz)[c]
13e	10.26	6.33	1.93–2.76	3.17 (d, 6 Hz)	5.26 (d, 12 Hz)[d] 5.66–6.20 (m)[e]

^{13}C-NMR Data	Ring Carbons						CHO	Alkyl Carbons		
	C-1	C-2	C-3	C-4	C-5	C-6		α-C	β-C	γ-C
13a	147.0	132.1	129.5	133.6	21.7	20.3	189.3	18.7	–	–
13b	147.6	138.2	130.4	132.6	22.2	20.7	190.3	25.4	13.1	–
13c	147.6	136.7	130.5	133.8	22.0	20.8	190.4	34.5	22.2	13.5
13d	147.5	142.6	130.8	130.5	22.0	20.7	190.1	28.5	22.0	–
13e	147.0	135.0	130.5	134.7	22.2	20.7	190.2	36.3	135.0	116.8

[a] In $CDCl_3$, ref. Me_4Si. – [b] Integrates for 1H, septet, J = 8 Hz. – [c] Integrates for 6H. – [d] Integrates for 2H. – [e] β-CH, integrates for 1H.

tons at δ 2.13–2.66. The remaining compounds gave good spectra (Table 2) in agreement with the ^{1}H-NMR data previously described.

The ^{13}C-NMR spectrum (Table 2) of aldehyde **13a** exhibited a total of eight resonances including the aldehydic carbon at δ 189.3. Four resonances (δ 147.0, 132.1, 129.5, and 133.6) were due to the vinylic carbons C-1, C-2, C-3, and C-4. The three remaining resonances at δ 21.7, 20.3, and 18.7 were assigned to the C-5 and C-6 of the cyclohexane ring, and to the 2-methyl group. An excellent correlation was found between the carbon resonances of **13a** and those of the four other compounds. The IR spectra (Table 3) for the α,β-unsaturated aldehydes all showed: (i) very strong carbonyl absorptions at 1650–1655 cm^{-1} which are characteristic of an α,β-unsaturated aldehyde; (ii) a strong absorption at 1540–1550 cm^{-1} for the α,β-unsaturated carbon-carbon double bond[6].

High-resolution mass spectral analyses of **13a–e** (Table 1) confirmed their molecular formulae. The fragmentation patterns of **13a–e** (Table 3) showed moderate (M + 2) peaks [with the exception of **13e**] indicative of the presence of ^{37}Cl, and strong molecular ions (due to ^{35}Cl), in the relative intensities to be expected from their isotopic abundances. The loss of chlorine from the molecules also resulted in peaks of high relative intensity. The fragmentation pattern also showed peaks for the loss of the aldehyde moiety and for the loss of both CHO group and alkyl side chain, again consistent with the assigned structures.

Characterization of 3-chloro-2-cyclohexen-1-ols: In the case of the reaction of the Vilsmeier reagent with ketone

Table 3. Mass spectral data and IR spectral maxima[a] [cm^{-1}] for aldehydes **13a–e**

	Fragmentation Pattern (Intensities)						IR Spectral Maxima			
	$M^+ + 2$	M^+	$M^+ - Alkyl$	$M^+ - Cl$	$M^+ - CHO$	$M^+ - CHO$, Alkyl	CHO (vs)	C=C–CHO (s)	Alkyl (m)	CH_3 (m)
13a	158 (16.7)	156 (50.7)	–	121 (59.0)	127 (20.6)	–	1650[b]	1540	2940–2850	1370
13b	172 (11.0)	170 (34.2)	141 (28.5)	135 (33.2)	141 (28.5)	113 (33.8)	1650	1550	2980–2880	1350
13c	186 (10.4)	184 (31.9)	141 (30.3)	149 (39.3)	155 (30.4)	113 (24.1)	1655	1550	2960–2880	1345
13d	186 (12.0)	184 (35.5)	141 (73.4)	149 (25.3)	–	113 (21.0)	1655	1550	2970–2860	1300
13e	184 (1.1)	182 (35.0)	141 (38.7)	147 (47.3)	–	113 (16.0)	1650	1550	2940–2860	1300

[a] Bromoform as solvent. – [b] Neat.

Table 4. Mass spectral data and IR spectral maxima [cm^{-1}] for allylic alcohols **12a–d**

	Fragmentation Pattern					IR Spectral Maxima			
	$M^+ + 2$ (%)	M^+ (%)	$M^+ - Cl$ (%)	$M^+ - Alkyl$ moiety (%)	$M^+ - H_2O$, Cl	OH (m)	Alkyl (s)	C=C (s)	C–O (s)
12a	111 (100.0)	–	93 (28.6)	–	–	3550, 3380	2940	1660	1060
12b	162 (1.9)	160 (5.8)	125 (100.0)	131 (72.0)	107 (22.6)	3580, 3420	2865	1670	1050
12c	176 (1.4)	174 (4.5)	139 (82.7)	131 (74.5)	121 (6.4)	3580, 3440	2870	1660	1060
12d	174 (1.6)	139 (21.5)	131 (100.0)	121 (5.7)	–	3420	2870	1670	1030

Table 5. ^1H- and ^{13}C-NMR chemical shifts (δ) for alcohols **12a–d**[a]

^1H-NMR Data	Cyclohexyl	Methine (t, 1H, 4 Hz)	Alkyl α-CH_2	Alkyl γ-CH_3
12a	1.72–2.33 (m, 7H)	4.13	–	1.72–2.33 (m)
12b	1.64–2.50 (m, 7H)	4.21	1.64–2.50 (m)	1.05 (t, 6 Hz)
12c	1.35–2.50 (m, 9H)[b]	4.20	1.35–2.50	0.89 (t, 7 Hz)
12d	1.50–2.41 (m, 7H)	4.34	3.13 (sep. 8 Hz)[c]	1.08 (d, 8 Hz) 1.16 (d, 8 Hz)

^{13}C-NMR Data	C-1	C-2	C-3	C-4	C-5	C-6	α-C	β-C	γ-C
12a	69.7	130.9	131.5	31.4	19.1	33.8	17.2	–	–
12b	67.2	131.9	136.3	31.5	18.9	34.0	24.3	12.2	–
12c	67.7	132.3	135.2	31.6	18.9	34.1	33.1	21.7	13.9
12d	64.9	131.4	138.6	31.5	18.1	34.3	30.6	21.2, 20.1	–

[a] In $CDCl_3$, ref. Me_4Si. – [b] Multiplet, 9H also includes β-CH_2. – [c] Integrates for 1H.

7a, the allylic alcohol **12a** was formed in considerable quantity; analysis indicated the formula $C_7H_{11}OCl$, i.e., formally simply the addition of HCl to 2-methyl-2-cyclohexen-1-one. IR data for **12a–d** (Table 4) showed absorptions at 3580 cm^{-1} for the free OH and a broad absorption for the H-bonded OH in the region of 3300–3500 cm^{-1}. The alkyl νC–H was seen at about 2870 cm^{-1} for **12a** while the alkene νC=C was observed at 1660–1670 cm^{-1} (Table 4).

An X-ray crystal structure study of **12a** was used to confirm the position of the OH group. The molecular structure is shown in Figure 1. The cyclohexene ring is in a half-chair conformation with the OH group quasiaxial. The Cl–C(1)=C(2)–C(2a) group is planar. The distances and angles in the molecule are close to the expected values.

The ^1H-NMR spectra of **12a–d** (Table 5), were compatible with the structures, although complex with much overlap between the resonances of the alkyl side chains and those

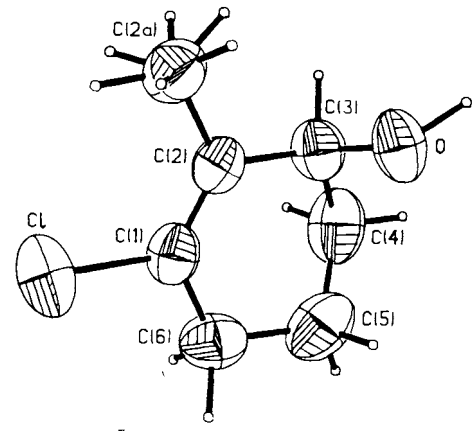


Figure 1. A perspective view of the alcohol **12a** with atom numbering. Hydrogen atoms are plotted on an arbitrary scale; both orientations of the methyl group hydrogens are shown. Bond lengths [Å] and angles [°] involving non-hydrogen atoms: C(1)–C(2) 1.315(4); C(2)–C(3) 1.506(4); C(2)–C(2a) 1.509(5); C(3)–C(4) 1.508(5); C(3)–O 1.440(4); C(4)–C(5) 1.493(6); C(5)–C(6) 1.526(7); C(6)–C(1) 1.494(5); C(1)–Cl 1.757(3); Cl–C(1)–C(2) 119.8(2); Cl–C(1)–C(6) 112.9(2); C(2)–C(1)–C(6) 127.3(3); C(1)–C(2)–C(2a) 125.2(3); C(1)–C(2)–C(3) 119.1(3); C(2a)–C(2)–C(3) 115.7(3); C(2)–C(3)–O 107.6(2); C(2)–C(3)–C(4) 113.0(3); O–C(3)–C(4) 111.2(3); C(3)–C(4)–C(5) 111.0(3); C(4)–C(5)–C(6) 110.1(3); C(1)–C(6)–C(5) 110.5(3).

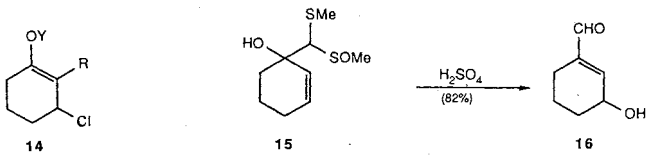
of the cyclohexyl ring. The resonance assigned to the methine proton was seen as a triplet at δ 4.13 integrating for one proton with J 4.0 Hz. The remainder of the protons resonated as a complex multiplet at δ 1.72–2.33.

The ^{13}C-NMR spectra of **12a–d** (Table 5) were more useful in confirming their structures. Two resonances in the olefinic range (at δ 131.5 and 130.9), one at 69.7 ppm (assignable to an alcohol carbon) and four alkyl carbons were seen in the ^{13}C-NMR spectrum of alcohol **12a**. The C-5 resonance appeared upfield of the ring carbons followed by the C-4 carbon (31.4 ppm) and the allylic C-6 carbon (33.8).

The carbon of the methyl group was assigned to the signal at 17.2 ppm. The ^{13}C-NMR spectra of the remaining compounds, **12b–d**, showed good agreement with the assignments for **12a** with the resonances varying by less than 0.5 ppm for C-4, C-5, and C-6 in the series **12a–d**.

The mass spectral data for **12a** (Tables 1 and 4) also supported its structure, although no molecular ion for **12a** was seen: the alcohol lost 2H, H_2O, Cl, and "H_2OCl" to give peaks at *m/z* 144, 128 (6.6), 111 (100.0), and 93 (28.6), respectively. High-resolution mass spectral data (Table 1) for **12b–d** confirmed their molecular formulae. The mass spectral fragmentation patterns for **12b–d** (Table 4) also gave intense peaks indicative of the loss of Cl, the alkyl side chain, and dehydration followed by loss of Cl.

Reaction Mechanism: The formation of aldehydes **13** probably proceeds by attack of an iminium cation on an enol of type **11** (Scheme 1). Compounds **12** are formally derived from the 2-cyclohexen-1-ones **7** by addition of HCl. However, 1,4-addition of $Cl^{\ominus}$ to **8** would give **14** and the isomerization of **14** to **12** appears less likely than S_N2' attack by an oxyanion (as in Scheme 1). Moreover, reaction of ketones **7** with only $POCl_3$ in $CHCl{=}CCl_2$ did not afford any allylic alcohols **12**. The known allylic transposition of a hydroxy group during the hydrolysis of alcohol **15** to alcohol **16** under acidic conditions[7] supports the route to compounds **12** as proposed in Scheme 1. However, other mechanisms, including 1,3-shifts, cannot at present be ruled out.



Routes to Dihydrobenzaldehydes: The presently described transformation **7** to **10** provides a novel route to 5,6-dihydrobenzaldehydes. Previous methods for the preparation of 5,6-dihydrobenzaldehydes include the thermolysis of 5-acyl-5-methyl-1,3-cyclohexadienes[8,9] or of bicyclic compounds such as bicyclo[3.2.0]hept-2-en-7-ones[10,11] and oxabicyclo-[5.1.0]octa-2,4-dienes[12]. These methods have limited synthetic utility since the yields are often quite low and a number of products are obtained including a variety of isomeric dihydrobenzaldehydes as well as fully aromatized products. The aldol condensation of α,β-unsaturated aldehydes has been employed to prepare 5,6-dihydrobenzaldehydes in good yields[13,14]. A number of reports of Diels-Alder reactions leading to 5,6-dihydrobenzaldehydes have also appeared[15–17] but often the dihydrobenzaldehyde is merely an unwanted by-product[18,19]. 5,6-Dihydrobenzaldehydes have also been prepared by the Diels-Alder reaction of α-arylseleno-α,β-unsaturated aldehydes with dienes, affording the tetrahydrobenzaldehyde and, after oxidative deselenation, the corresponding 5,6-dihydrobenzaldehyde in good overall yields[20,21]. Recently, the conversion of oxatricyclic alcohols to the corresponding 5,6-dihydrobenzaldehyde has been effected using $TiCl_4$ as a catalyst[22].

Experimental

All boiling points and melting points are uncorrected. – IR spectra were obtained on a Perkin-Elmer 283B infrared spectrophotometer. ^{1}H-NMR spectra were obtained on a Varian EM 360 L (60 MHz) NMR spectrometer or on a Varian XL-200 (200 MHz) NMR spectrometer, with tetramethylsilane (TMS) as internal standard. – ^{13}C-NMR spectra were obtained on a Jeol FX-100 (25 MHz) NMR spectrometer or on a Varian XL-200 (50 MHz) NMR spectrometer, referenced to the solvent (δ $CDCl_3$ = 77.0). – Low and high resolution mass spectra were obtained on an AEIMS30 mass spectrometer. – Microanalyses were performed under the supervision of Dr. R. W. King (University of Florida) or by Atlantic Microlabs, Atlanta, Georgia. – Commercially available reagent grade solvents and reagents were used without further purification. Phosphorus oxychloride and 4-formylmorpholine were obtained from Aldrich Chemical Company, Inc. – Silica gel chromatography utilized either E. M. Merck or MCB silica gel 60 (230–400 mesh).

The following were prepared by literature methods[4,5]: *2-Methyl-2-cyclohexen-1-one*[5] (22% yield), bp 99–120°C/80 Torr, lit. bp 98–101°C/77 Torr; *2-propyl-2-cyclohexen-1-one*[4] (27% yield), bp 64–66°C/2 Torr, lit. bp 65–66°C/2.4 Torr; 2-isopropyl-2-cyclohexen-1-one[4] (28% yield), bp 57–59°C/2 Torr, lit. bp 56–58°C/2.3 Torr; *2-allyl-2-cyclohexen-1-one*[4] (29% yield), bp 66–68°C/3 Torr, lit. bp 67–68°C/3.2 Torr.

2-Ethyl-2-cyclohexen-1-one (**7b**) was prepared by a modification of the literature method[4] using iodoethane as the alkyl halide. The residual oil was distilled through a 10-cm Vigreux column to give **7b** (2.4 g, 20%) as an oil, bp 87–90°C/13 Torr. – ^{1}H NMR ($CDCl_3$): δ = 1.03 (3H, t, *J* = 8 Hz, CH_3), 1.76–2.69 (8H, br m, 4 CH_2), 6.93 (1H, t, *J* = 4 Hz, CH). – ^{13}C NMR ($CDCl_3$): δ = 12.2 (Et-C_2), 22.0 (Hex-C_5), 22.7 (Et-C_1), 25.5 (Hex-C_4), 38.0 (Hex-C_6), 140.5 (Hex-C_2), 143.4 (Hex-C_3), 198.6 (Hex-C_1). – IR (neat): 2990–2830 cm^{-1} (s, br), 1660–1630 (s, br), 1430, 1380, 1320 (w), 1250 (w), 1170, 1100, 1080 (w), 960 (w), 900, 860, 700. – MS: *m/z* (rel. intensity) = 124 (67.6), 109 (12.7), 96 (100.0), 81 (25.6), 67 (39.1). High-resolution mass spectrum (*m/z*): Calcd. for $C_8H_{12}O$, 124.0888, Found 124.0896.

General Method for the Preparation of 1-Formyl-2-chloro-3-alkyl-1,3-cyclohexadienes (**13**) *and 2-Alkyl-3-chloro-2-cyclohexen-1-ols* (**12**): The ketone (1.5 g) was added at 25°C over 2 min to the Vilsmeier reagent (prepared by adding $POCl_3$ (7 g, 45 mmol) over 5 min to a stirred mixture of 4-formylmorpholine (6 ml, 59 mmol) and trichloroethylene (10 ml) at 5°C). The resulting mixture was stirred at 25°C for 2 h and then methylene chloride (25 ml) and a solution of sodium carbonate (12.5 g) in water (75 ml) were added and the solution was stirred for an additional 20 min at pH 7. The aqueous layer was extracted with methylene chloride (3 × 50 ml) and the combined organic layers were washed with water (2 × 60 ml), then dried over $MgSO_4$. Purification by column chromatography on silica gel (150 g) provided the aldehyde **13** and the allylic alcohols **12**; for details see Table 1.

Crystal data for **12a** ($C_7H_{11}OCl$, M_w = 146.63), tetragonal space group $I4_1/a$, *a* = *b* = 19.807(3), *c* = 7.819(1) Å, *U* = 3067(1) Å^3, *Z* = 16, D_x = 1.27 g cm^{-3}. Syntex $P\bar{1}$ diffractometer, 1202 reflections measured, of which 873 unique observed [$F_o/\sigma(F_o) \geq 2$]. Direct methods revealed positions of all non-H atoms; H atoms were located in a difference map. The refinement of 82 parameters gave final *R* = 0.049 and R_w = 0.039 ($w = 1/\sigma^2$). The atomic coordinates and thermal parameters have been deposited at Cambridge Crystallographic Data Centre, University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW, England. Any request should be accompanied by the full literature citation for this paper.

Table 6. Final atomic coordinates ($\times 10^4$) and isotropic thermal parameters ($\times 10^3$) for 3-chloro-2-methyl-2-cyclohexen-1-ol (**12a**).

Atom	x	y	z	U
Cl	3568(1)	2877(1)	4407(1)	89(1)
C(1)	3377(2)	3142(2)	2318(4)	59(1)
C(2)	2810(2)	3465(2)	2014(4)	55(1)
C(2A)	2298(2)	3664(2)	3350(4)	75(1)
C(3)	2637(2)	3655(2)	201(4)	63(1)
O	2723(1)	4374(1)	40(2)	68(1)
C(4)	3054(2)	3281(2)	-1107(4)	86(2)
C(5)	3786(2)	3301(2)	-656(5)	90(2)
C(6)	3905(2)	2945(2)	1048(5)	76(1)

Equivalent isotropic U defined as one third of the trace of the orthogonalized U_{ij} tensor.

2-Chloro-1-formyl-3-isopropyl-1,3-cyclohexadiene (**13d**) *and 3-Chloro-2-isopropyl-2-cyclohexen-1-ol* (**12d**): The reactions with 2-isopropyl-2-cyclohexen-1-one[4] were carried out under three different conditions: (i) 5 h reaction time and 10 min for the hydrolysis to give **13d** (0.3 g, 15%) as a yellow oil and **12d** (88 mg, 5%); (ii) 24 h reaction time, hydrolysis for 2 h to give **13d** (0.48 g, 24%) only; (iii) 20 h reaction time, neutralization with aqueous sodium hydroxide to pH = 10, and hydrolysis for 2 h gave **13d** (0.4 g, 20%) only.

CAS Registry Numbers

7a: 1121-18-2 / **7b**: 31863-60-2 / **7c**: 59034-18-3 / **7d**: 59034-19-4 / **7e**: 38019-50-0 / **12a**: 108035-76-3 / **12b**: 113088-70-3 / **12c**: 113088-71-4 / **12d**: 113108-87-5 / **13a**: 108035-74-1 / **13b**: 113088-66-7 / **13c**: 113088-67-8 / **13d**: 113088-68-9 / **13e**: 113088-69-0 / 4-formylmorpholine: 4394-85-8

[1] The following communications are considered as Parts I–IV respectively of this series: [1a] A. R. Katritzky, C. M. Marson, *Tetrahedron Lett.* **26** (1985) 4715. – [1b] A. R. Katritzky, C. M. Marson, *J. Org. Chem.* **52** (1987) 2726. – [1c] A. R. Katritzky, C. M. Marson, Z. Wang, *J. Org. Chem.* **52** (1987) 2730. – [1d] A. R. Katritzky, C. M. Marson, G. J. Palenik, A. E. Koziol, H. Luce, M. Karelson, B.-C. Chen, W. Brey, *Tetrahedron*, in press.

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