containing 5% silver nitrate, using 20% ether in benzene as eluent. Bands were detected by ultraviolet light, separated, and extracted with ether. Only two products were isolated, and both were shown by infrared spectroscopy to be unsaturated ketones. The more easily eluted product was not obtained free from saturated ketone even on repeated chromatography. The less mobile product crystallized from methanol–water as colorless prismatic needles, mp 106°. The nmr spectrum showed a singlet at δ 6.2 integrating for one proton (vinylic) and a doublet at δ 1.61 (J = 1 cps) integrating for three protons (methyl group attached to double bond), indicating that the compound was **3-methyl-4,4-diphenyl-Δ^2-cyclohexenone (XXII).** *Anal.* Calcd for $C_{19}H_{18}O$: C, 86.99; H, 6.92; mol wt, 262. Found: C, 86.57; H, 6.86; mol wt (mass spectroscopy), 262.

4,5-Dimethyl-Δ^2-cyclohexenone (XXIII). 3,4-Dimethylcyclohexanol was oxidized by Jones' reagent[10] to 3,4-dimethylcyclohexanone. Bromination and dehydrobromination as already described gave a mixture of unsaturated ketones, which was separated by glpc (10-ft 20% IGEPAL on 60–80 Chromosorb W, 150°). The most abundant product was shown by infrared (λ_{max}^{film} 5.95 μ) and ultraviolet (λ_{max} 228 mμ) spectra to be 4,5-dimethyl-Δ^2-cyclohexenone. *Anal.* Calcd for $C_8H_{12}O$: C, 77.37; H, 9.74; mol wt, 124. Found: C, 77.24; H, 9.57; mol wt (mass spectroscopy), 124. The other isomer was not characterized further.

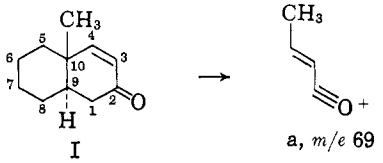
Mass Spectrometry in Structural and Stereochemical Problems. CXXXIV.[1] Electron Impact Induced Alkyl and Aryl Rearrangements in α-Arylidene Cyclic Ketones[2]

R. L. N. Harris,[3a] F. Komitsky, Jr.,[3b] and Carl Djerassi

Contribution from the Department of Chemistry, Stanford University, Stanford, California 94305. *Received April 4, 1967*

Abstract: The mass spectra of a number of alkyl- and aryl-substituted α-arylidene cyclic ketones have been measured and the mechanism and scope of an electron impact induced alkyl (aryl) rearrangement occurring in these compounds is examined. Other fragmentation processes occurring in this class of compounds are also discussed.

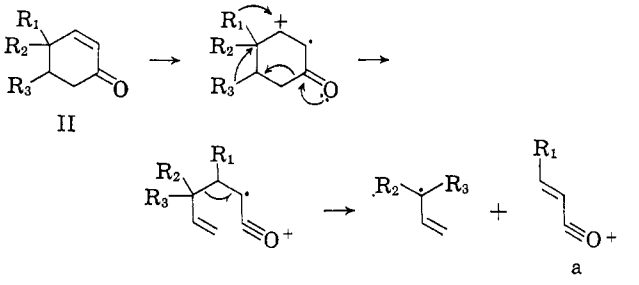
Ketones of type I display a prominent peak in their mass spectra at *m/e* 69 which has been shown[4] to be due to the formation of the ion a, arising from a 1,2 rearrangement of the angular methyl group from C-10 to C-4 prior to fragmentation. In an earlier paper[5] the mechanism and scope of this rearrangement was discussed and it was found to occur in ketones of general formula II where R_1 = H, Me, Et, and Ph, and R_2 and R_3 are either methyl groups or part of a second alicyclic ring (five, six, or seven membered) Of particular interest was the fact that certain closely related ketones (II, R_3 = H) did not display any significant



I a, *m/e* 69

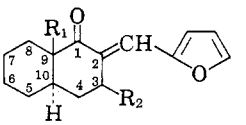
rearrangement ions in their mass spectra. From this and other evidence it was concluded that the C-5 alkyl substituent was implicated in the rearrangement process; of the various plausible mechanistic rationalizations outlined earlier[5] only that summarized in Scheme I is compatible with all of the experimental results.

Scheme I

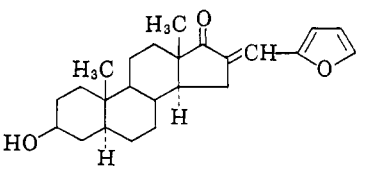


II a

An earlier communication[6] has drawn attention to the occurrence of a related rearrangement in the mass spectra of 2-arylidene-1-decalones. Thus, the base peak in the mass spectrum of *trans*-2-furfurylidene-9-methyl-1-decalone (III) and the analogous steroidal D-homo ketone IV occurs at *m/e* 121 and was shown by exact mass measurements to correspond to C_8H_9O. This peak was shifted to *m/e* 124 in the spectrum of the 9-d_3-methylated analog IIIa and to *m/e* 122 in that of the 3-d_1 analog IIIb, whereas in the spectrum of the compound lacking the angular methyl group (V) the base



III, R_1 = Me, R_2 = H
IIIa, R_1 = CD_3, R_2 = H
IIIb, R_1 = Me, P_2 = D
V, R_1 = H, R_2 H



IV

(1) For paper CXXXIII see P. Brown and C. Djerassi, *Angew. Chem.*, in press.

(2) Financial assistance by the National Institutes of Health (Grants No. AM-04257 and CA-07195) is gratefully acknowledged. The purchase of the Atlas mass spectrometer was made possible through NASA Grant NsG 81-60.

(3) Postdoctoral Research Fellow: (a) 1965–1966; (b) 1964–1965.

(4) F. Komitsky, Jr., J. E. Gurst, and C. Djerassi, *J. Am. Chem. Soc.*, **87**, 1398 (1965).

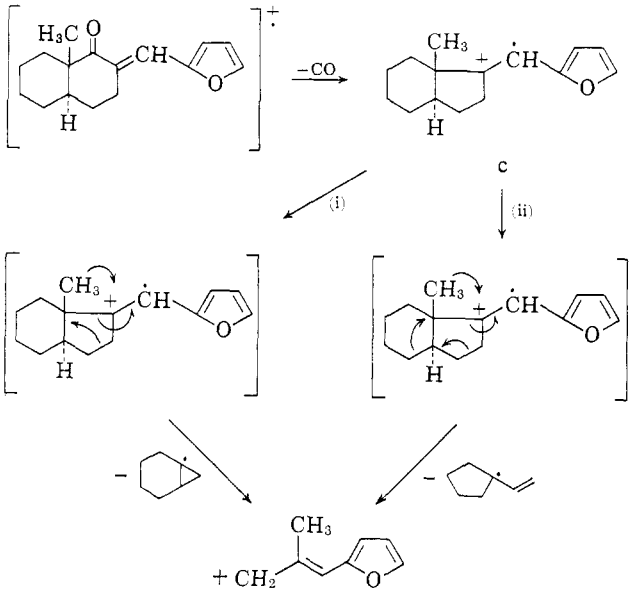
(5) R. L. N. Harris, F. Komitsky, Jr. and C. Djerassi, *ibid.*, **89**, 4765 (1967).

(6) C. Djerassi, A. M. Duffield, F. Komitsky, Jr., and L. Tökes, *ibid.*, **88**, 860 (1966).

peak occurred at *m/e* 107. Appropriate mass shifts were encountered in the benzylidene (*m/e* 131), *p*-chlorobenzylidene (*m/e* 165–167), and *p*-methylbenzylidene (*m/e* 145) analogs of III. In those examples where both *cis*- and *trans*-ring-fused isomers were isolated, there were no significant differences in their mass spectra.

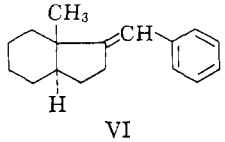
From these results it was concluded[6] that the intense *m/e* 121 peak in the spectrum of III was due to ion b, which contains the furfurylidene moiety, together with the adjacent carbon atoms 2 and 3 and the bridgehead C-9 methyl substituent. This ion must have arisen by a rearrangement process in which the angular methyl group migrates from its position at the ring junction to C-2 prior to fragmentation. Two possible mechanistic alternatives were proposed to account for this rearrangement, and they are set out in Scheme II. Both mechanisms involve at first the loss of carbon monoxide to give the ionized 1-furfurylidene-8-methylhydrindan (c), which may fragment by either of two pathways (i and ii) to give the charged species b.

Scheme II



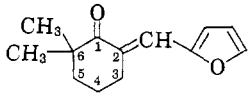
b, *m/e* 121

In support of the first step (carbon monoxide ejection), common to both rearrangement sequences, it was shown that the mass spectrum of the benzylidenehydrindan VI (analogous to the intermediate (M − CO) species c, Scheme II) also exhibited an intense rearrangement ion at *m/e* 131, corresponding to b (furfuryl replaced by phenyl). It should be noted that

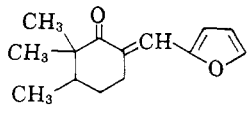


VI

the two alternatives (i and ii) in Scheme II proposed to account for the methyl migration and concomitant bond fissions are directly analogous to those considered for the related electron impact induced methyl migration in α,β-unsaturated cyclic ketones.[4,5] As in the unsaturated ketone series the two pathways may be distinguished by a consideration of the scope of the rearrangement; for example, if the rearrangement follows path i then ketones such as VII which have no substituent at C-5 (corresponding to the site of ring juncture in the decalone III) should still show the rearrangement peak (*m/e* 121). However, if the rearrangement follows path ii, then C-5 alkylated cyclohexanones such as VIII should display the rearrangement peak, while VII should not.



VII



VIII

Accordingly the 2-furfurylidene-6,6-dimethyl- and 5,6,6-trimethylcyclohexanones (VII and VIII, respectively) were prepared and their mass spectra measured. The present paper considers the mechanistic implications of these results and further delineates the scope of the rearrangement by a consideration of the mass spectra of α-arylidene cyclic ketones in which the migrating group is methyl, ethyl, or phenyl and the aryl group is furfuryl, phenyl, or substituted phenyl (see Table I). The influence of ring size and the effect of the stereochemistry of the ring juncture in bicyclic ketones on the rearrangement process are also considered. The involvement of the M − CO species in the rearrangement process (see Scheme II) has been inferred by measuring the mass spectra of two related benzylidenehydrindans and a benzylidenecyclopentane.

Synthetic Studies

2-Arylidene-9-alkyl-1-decalones were prepared by base-catalyzed condensation of the appropriate aldehyde with 1-decalone[7] followed by alkylation at C-9. In some instances the mixture of *cis* and *trans* isomers was separated by fractional crystallization; in others the mixture was used directly for mass spectral examination. The same general approach was utilized in the synthesis of the 2-arylidene-6,6-dialkylcyclohexanones.

2-Furfurylidene-5,6,6-trialkylcyclohexanones (VIII) were obtained by condensation of 2,3-dimethylcyclohexanone (prepared from the corresponding phenol[8]) with furfural followed by alkylation.

A somewhat more circuitous route had to be employed for 2-furfurylidene-5,6-dimethyl-6-phenylcyclohexanone (XXII). 4,5-Dimethyl-4-phenyl-Δ^2-cyclohexenone[5] was converted to the 2,3-epoxide which was reduced with hydrazine[9] to a mixture of epimeric 5,6-dimethyl-6-phenyl-Δ^2-cyclohexenols. Jones oxidation[10] of the mixture gave 5,6-dimethyl-6-phenyl-Δ^2-cyclohexenone which was hydrogenated (at atmospheric pressure over 10% palladium on carbon catalyst in ethyl acetate) and condensed as before with furfuraldehyde to give the required 2-furfurylidene derivative.

cis-1-Benzylidene-8-methylhydrindan (VI) was obtained from *cis*-8-methyl-1-hydrindanone,[11] which was treated with excess benzylmagnesium chloride in ether

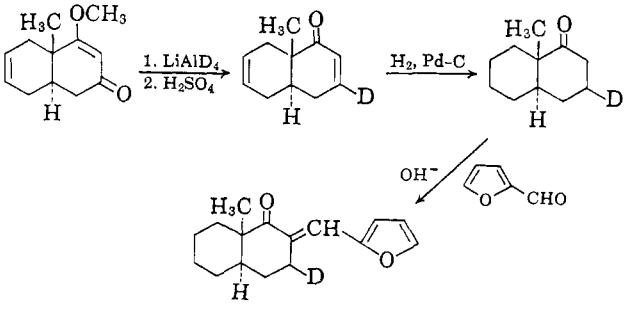
(7) W. S. Johnson, B. Bannister, and R. Pappo, *J. Am. Chem. Soc.*, **78**, 6336 (1956).
(8) (a) H. E. Ulery and J. H. Richards, *ibid.*, **86**, 3113 (1964); (b) W. Hückel and M. G. E. Ibrahim, *Ber.*, **91**, 1970 (1958).
(9) M. P. Cava and B. R. Vogt, *J. Org. Chem.* **30**, 3775 (1965).
(10) K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. Weedon, *J. Chem. Soc.*, 39 (1946).
(11) W. S. Johnson, *J. Am. Chem. Soc.*, **66**, 215 (1944).

and the resulting alcohol dehydrated with phosphorus oxychloride in pyridine. A mixture of the exocyclic (VI) and endocyclic (*cis*-1-benzyl-8-methylhydrindene) products was isolated, but its separation was readily effected by vapor phase chromatography. The synthesis of the related model compound, 1-benzylidene-2,2,3-trimethylcyclopentane (XXIII), utilized as starting material 2,2,3-trimethylcyclopentanone, which was prepared from the corresponding cyclohexanone furfurylidene derivative following the procedure[11] used in the preparation of 8-methylhydrindanone from 9-methyl-2-furfurylidene-1-decalone. Reaction of the cyclopentanone with benzylmagnesium chloride followed by dehydration gave a mixture of benzylidenecyclopentane and benzylcyclopentene which was separable by vapor phase chromatography.

The deuterium-labeled compounds were generally prepared by the same methods used for the unlabeled analogs. Thus α'-methyl-d_3-α-arylidene ketones were synthesized by alkylation of the appropriate arylidene ketone with methyl-d_3 iodide. α'-Deuterated α-arylidene ketones were prepared by exchanging the α' hydrogen in methanol-d_1 and heavy water in the presence of base.

The synthesis of *trans*-2-furfurylidene-9-methyl-1-decalone-3-d_1 (IIIb) is outlined in Scheme III. *trans*-9-Methyl-3-oxo-1-methoxy-$\Delta^{1,6}$-hexahydronaphthalene[12] was reduced with lithium aluminum deuteride and the product treated with sulfuric acid to give *trans*-9-methyl-1-keto-$\Delta^{2,6}$-hexahydronaphthalene-3-d_1. The unsaturated ketone was reduced at room temperature over palladium-on-carbon catalyst to *trans*-9-methyl-1-decalone-3-d_1 which was condensed with furfural to yield the required 2-furfurylidene derivative IIIb. The corresponding benzylidene derivative was prepared in the same manner using benzaldehyde instead of furfural in the final step.

Scheme III



Discussion of the Mass Spectra

The Rearrangement Ion. The results listed in Table I show that the rearrangement ion (of type b) is a prominent feature in the mass spectra of many α-arylidene-α'-methyl cyclic ketones, in many instances being the base peak of the spectrum. The intensity of this ion is recorded both as per cent total ionization (% $\Sigma_{40}{}^{M^+}$) and as per cent abundance relative to the most intense peak (% RA); the same data are also presented for both the molecular ion (M^+) and the M − CO ion where applicable. As noted in Table I, many of the spectra were measured at both 70 and 12 ev. High-resolution mass spectrometry was employed to confirm in every instance the molecular composition of the appropriate ions. Further evidence for the structure of the rearrangement ion is given by the deuteration studies (see last column in Table I), which show conclusively that both the angular methyl substituent (at C-9 in the decalones and C-6 in the cyclohexanones) and the C-3 carbon atom are incorporated in the rearrangement species. Appropriate mass shifts for this ion in the mass spectra of other arylidenedecalones (X–XIII) demonstrate that in every case the arylidene moiety forms part of the rearrangement ion. Structure b for this ion is in complete accord with these observations.

Several examples are also presented in which the migrating group is ethyl (XVII, XVIII, XXI), hydrogen (V, XIV–XVI), and phenyl (XXII). Again, deuteration studies support the structures assigned to the rearrangement ion in all except the last of these examples.

The two mechanistic paths proposed[6] for the formation of ion b have in common the loss of carbon monoxide in the first step (see Scheme II), giving rise to an intermediate which may be formulated as an ionized furfurylidenehydrindan (c). The mass spectra of the benzylidenehydrindan VI and its 8-methyl-d_3 analog VIa display intense peaks at *m/e* 131 and 134, respectively, indicating that these compounds also give rise to the ion involving rearrangement of the angular methyl group. This alone is insufficient evidence to prove the intermediacy of the arylidenehydrindan in the rearrangement process. However, consideration of the low-voltage spectra (Table I) reveals that, whereas the intensity of the M − CO peak increases markedly at lower ionizing potential, the intensity of the rearrangement ion in most cases decreases. This indicates that the loss of carbon monoxide is an energetically favorable primary fragmentation process, whereas the alkyl migration is less favorable and almost certainly represents a secondary process. There is strong evidence, therefore, that the M − CO species is in fact an intermediate in the rearrangement, as previously suggested (see Scheme II). The benzylidenecyclopentane derivative XXIII also displays a prominent rearrangement ion (*m/e* 131) in its mass spectrum, thus offering support in the monocyclic series for the intermediacy of an M − CO species in the rearrangement step.

Two pathways have been proposed for rearrangement and fragmentation of the M − CO species to give the rearrangement ion (see Scheme II), the distinguishing feature being the involvement of the C-5 alkyl substituent in one of them (path ii). Examination of the results in Table I shows that the abundance of the rearrangement ion in the ketone VII is very small, whereas in VIII, which differs from VII only in possessing a methyl substituent at C-5, the rearrangement ion is *eleven times* more abundant. Similarly the dimethyl benzylidene ketone XX shows very little rearrangement, whereas the C-5 substituted ketones XXI and XXII both show significant rearrangement ions. These results strongly suggest that the C-5 alkyl substituent is involved in the rearrangement process, a striking parallel to the conclusions reached about the course of alkyl rearrangement in α,β-unsaturated cyclic ketones.[5]

A careful scrutiny of the relevant mass spectra has revealed in every example the appropriate meta-

(12) C. Djerassi, E. Lund, and A. A. Akhrem, *J. Am. Chem. Soc.*, **84**, 1249 (1962).

Table I. Electron Impact Induced Alkyl and Aryl Migrations in Cyclic α-Arylidene Ketones

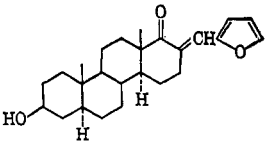
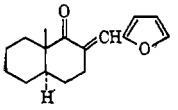
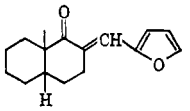
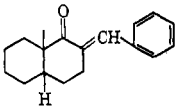
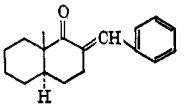
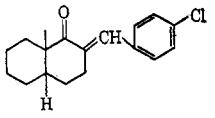
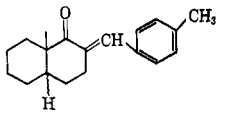
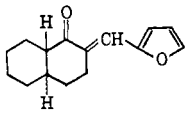
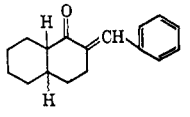
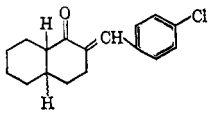
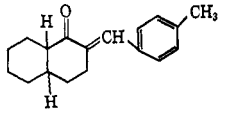
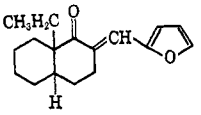
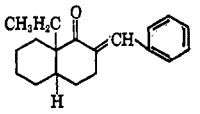
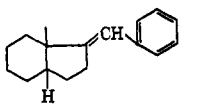
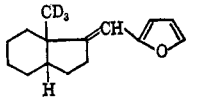
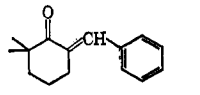
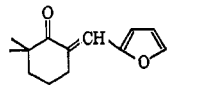
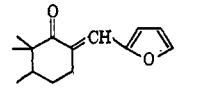
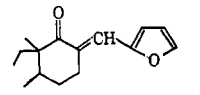
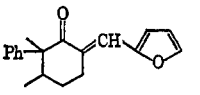
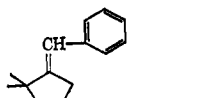
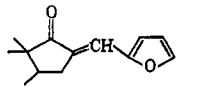
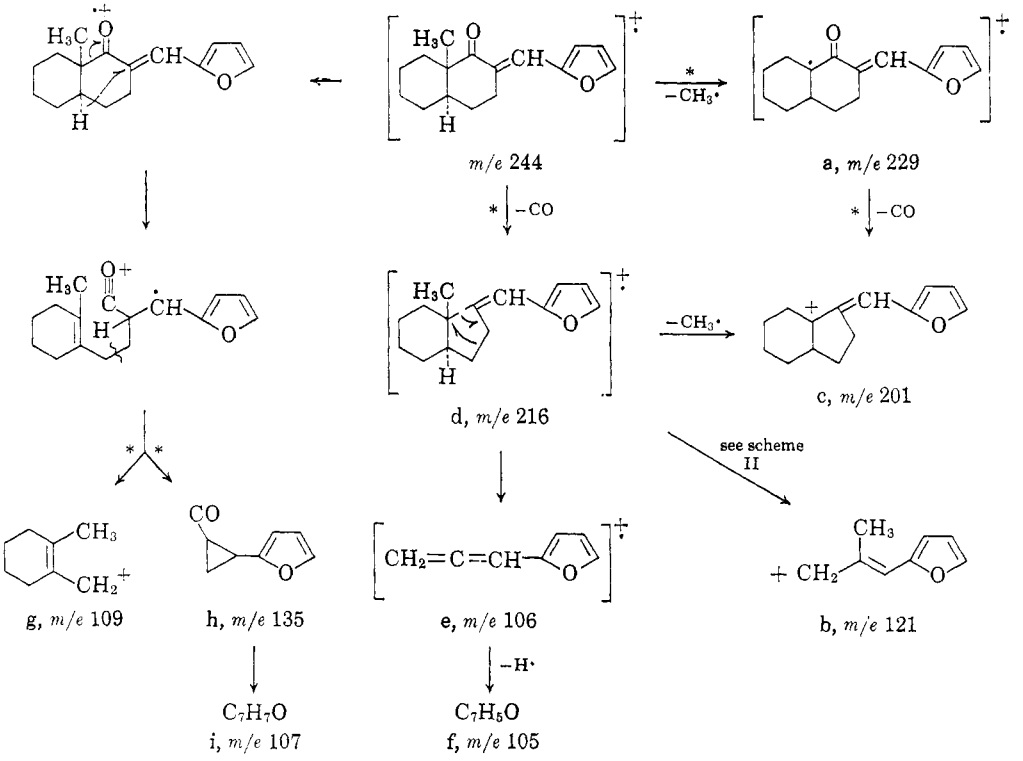
Compd	M+, 70 ev % Σ_{40}^{M+}	M+, 70 ev % RA	M+, 12 ev % Σ_{40}^{M+}	M+, 12 ev % RA	—M − CO,— 70 ev % Σ_{40}^{M+}	—M − CO,— 70 ev % RA	—M − CO,— 12 ev % Σ_{40}^{M+}	—M − CO,— 12 ev % RA	*m/e*	Rearrangement ion, 70 ev % Σ_{40}^{M+}	Rearrangement ion, 70 ev % RA	Rearrangement ion, 12 ev % Σ_{40}^{M+}	Rearrangement ion, 12 ev % RA	Deuterated analogs
 IV[c,f]	1.5	20			2.0	27			121	7.4	100			18-Methyl-d_3 (IVa), *m/e* 121 → 124
 III[c,f]	3.3	46			2.9	41			121	7.1	100			9-Methyl-d_3 (IIIa), *m/e* 121 → 124 3-d_1 (IIIb), *m/e* 121 → 122
 IX[c,f]	2.9	34			3.9	45			121	8.6	100			
 X[a,f]	4.7	57	17.6	59	8.2	100	29.8	100	131	4.0	48	3.0	10	9-Methyl-d_3 (Xa), *m/e* 131 → 134
 XI[a,f]	4.7	57	11.0	82	6.2	68	13.4	100	131	3.2	35	4.3	32	3-d_1 (XIa), *m/e* 131 → 132
 XII[a]	1.3	22	8.6	29	7.5	133[d]	38	133[d]	165[d] 167	4.1	73	3.4	12	
 XIII[a]	4.0	77	20.9	100	5.1	100	18.9	90	145	4.5	88	4.2	20	
 V[c,f]	4.5	33			2.2	16			107	13.6	100			
 XIV[c,f]	4.8	53			1.2	13			117	9.2	100			9-d_1 (XIVa), *m/e* 117 → 118
 XV[c]	1.9	32			1.5	26			151[d] 153	6.3	109			
 XVI[c]	2.1	20	20	100	0.8	8	17.9	90	131	10.4	100	4	20	

Table I (*Continued*)

Compd	M^+, 70 ev % Σ_{40}^{M+}	M^+, 70 ev % RA	M^+, 12 ev % Σ_{40}^{M+}	M^+, 12 ev % RA	—M − CO,— 70 ev % Σ_{40}^{M+}	—M − CO,— 70 ev % RA	—M − CO,— 12 ev % Σ_{40}^{M+}	—M − CO,— 12 ev % RA	*m/e*	Rearrangement ion, 70 ev % Σ_{40}^{M+}	Rearrangement ion, 70 ev % RA	Rearrangement ion, 12 ev % Σ_{40}^{M+}	Rearrangement ion, 12 ev % RA	Deuterated analogs
 XVII[c]	4.9	61			0.13	1.6[e]			135	1.0	13			
 XVIII[c]	0.9	11			0.2	2.5[e]			145	0.6	7			
 VI[c]	4.1	35							131	6.3	53			8-Methyl-d_3 (VIa), *m/e* 131 → 134
 XIX[b]	9.6	31			2.2	7			124	0.3	1			
 XX[c]	3.7	38			4.0	42[g]			131	0.7	7			
 VII[c]	3.6	32			4.2	37			121	1.0	9			
 VIII[a]	4.7	43	56	100	4.1	37	23.6	42	121	11.0	100	1.1	2	6-Methyl-d_3 (VIIIa), *m/e* 121 → 124, 121
 XXI[a]	3.1	25			1.9	15.4[e]			121 135	1.7 0.5	14 4			2-β-Ethyl-d_3 (XXIa),[c] *m/e* 135 → 138
 XXII[b]	8.0	59			13.5	100			121 183	5.0 2.0	37 15			
 XXIII[b]	3.7	35	53.8	100					131	9.3	74	3.8	7	
 XXIV[b]	8.8	25			2.1	6			121	0.7	2			

[a] Mass spectrum recorded on an AEI MS-9 mass spectrometer. [b] Mass spectrum recorded on an Atlas CH-4 spectrometer. [c] Mass spectrum recorded on a CEC Model 21-103C mass spectrometer. [d] This value includes contributions from both ions containing the two isotopes of chlorine. [e] Calculated as the M − CO peak by subtracting the proportion of M − C_2H_4 as determined by high-resolution mass spectrometry. [f] The authors wish to thank Professor W. S. Johnson of this department for a generous gift of this compound. [g] High-resolution mass measurements showed that no M − C_2H_4 ion was produced.

Scheme IV. Major Fragmentation Pathways of *trans*-2-Furfurylidene-9-methyl-1-decalone (III) after Electron Impact



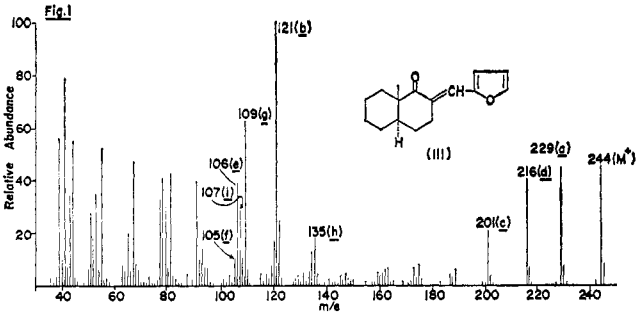


Figure 1. Mass spectrum of *trans*-2-furfurylidene-9-methyl-1-decalone (III); see Scheme IV.

stable ion for the loss of carbon monoxide from the molecular ion, a result to be expected in view of the ease of this fragmentation process. However, the generation of the rearrangement ion b from the M − CO precursor was supported in only one instance by the appearance of a metastable ion—in the mass spectrum of 2-furfurylidene-5,6,6-trimethylcyclohexanone (VIII).

In conclusion it may be stated that the electron impact induced migration of an alkyl group in α-arylidenecyclohexanones and -decalones takes place after loss of carbon monoxide from the molecular ion in what is most probably a concerted process involving participation of another alkyl substituent at C-5 in the cyclohexanones (C-10 in the corresponding decalones), as indicated by path ii, Scheme II.

Other Fragmentation Processes

Since nothing has so far been published on the electron impact induced fragmentation of arylidene ketones and related compounds, we summarize below some of their typical decomposition modes.

***trans*-2-Furfurylidene-9-methyl-1-decalone (III).** The mass spectrum is shown in Figure 1, and the major fragmentation pathways (asterisks denote presence of the appropriate metastable peak) are set out in Scheme IV; supporting evidence from deuteration studies is summarized in Table II. It should be recognized that the structures given in this and the subsequent schemes are used for illustrative purposes only to describe the over-all course of the fragmentations and may bear little relation to the actual structures of the ions. As can be seen from Scheme IV there are several major fragmentation pathways: loss of a methyl radical and/or carbon monoxide leads to fragments a, c, and d, while subsequent bond fissions in d afford b, e, and f. Hydrogen transfer (provisionally postulated from C-10) followed by cleavage and subsequent loss of carbon monoxide leads to ions g, h, and i, thus accounting for most of the abundant peaks in the upper mass range of Figure 1. The mass spectrum of the *cis* isomer IX is almost identical. Analogous fragmentations also occur in the arylidene series (X–XIII).

Table II. Summary of Major Fragment Ions of *trans*-2-Furfurylidene-9-methyl-1-decalone (III) and Deuterated Derivatives

Compd	M+	Fragment ions, m/e								
		a	b	c	d	e	f	g	h	i
III	244	229	121	201	216	106	105	109	135	107
IIIa	247	229	124	201	219	106	105	112	135	107
IIIb	245	230	122	202	217	107	106	109	136	108

***cis*-1-Benzylidene-8-methylhydrindan (VI) (Figure 2).** The main fragmentation pathways are summarized in Scheme V, with supporting evidence from deuteration studies set out in Table III. Again, the rearrangement ion b is a prominent feature of the mass spectrum, but now the base peak d (*m/e* 91) is the tropylium cation, arising from a hydrogen migration and subsequent

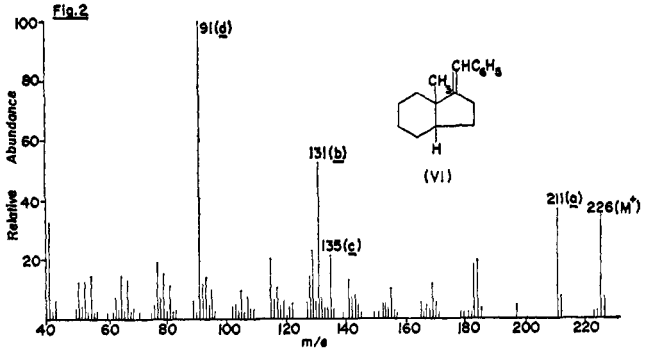


Figure 2. Mass spectrum of *cis*-1-benzylidene-8-methylhydrindan (VI); see Scheme V.

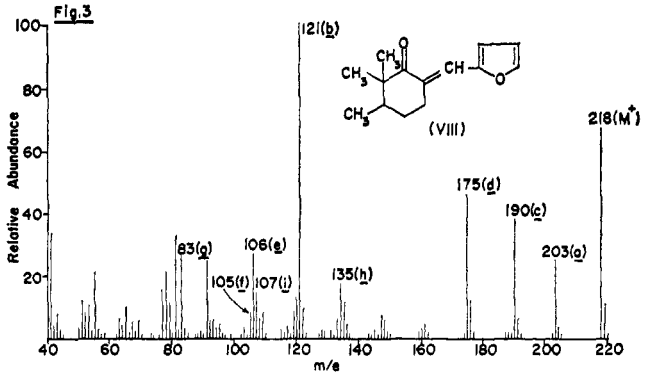
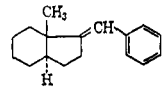
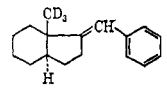


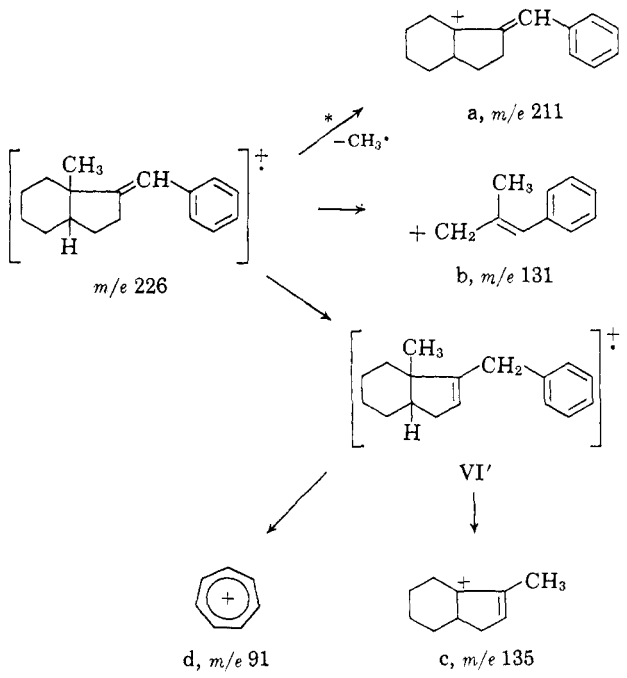
Figure 3. Mass spectrum of 2-furfurylidene-5,6,6-trimethylcyclohexanone (VIII); see Scheme VI.

Table III. Summary of Major Fragment Ions of *cis*-1-Benzylidene-8-methylhydrindan (VI) and Its 8-Methyl-d_3 Derivative (VIa)

Compd	M+	*m/e* values for fragment ions a	b	c	d
 VI	226	211	131	135	91
 VIa	229	211	134	135	91

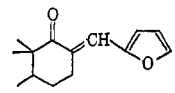
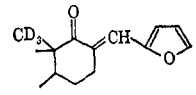
benzylic cleavage as depicted in Scheme V. There is some charge retention on the alicyclic part of the molecule after this cleavage, giving rise to the ion of mass 135, probably best represented as the allyllically stabilized tertiary carbonium ion c. It is of interest that the isomeric *cis*-1-benzyl-8-methyl-Δ^1-hydrindene (VI′), which was obtained as a by-product in the synthesis of VI, has a very similar mass spectrum with prominent peaks at *m/e* 91 (base peak), 135, and 211, but no significant peak at *m/e* 131.

Scheme V. Major Fragmentation Pathways of *cis*-1-Benzylidene-8-methylhydrindan (VI) after Electron Impact



2-Furfurylidene-5,6,6-trimethylcyclohexanone (VIII) (Figure 3). The principal modes of fragmentation (Scheme VI) show a striking parallel to those of the furfurylidene decalone (III, Scheme IV). Again, the principal ions are generated by three main pathways: the alkyl rearrangement leading to the base peak b at *m/e* 121, loss of carbon monoxide and/or a methyl radical giving ions a, c, d, and subsequently e and f, and the hydgroen rearrangement and cleavage giving rise to ions g, h, and i. Similar mass spectra are shown by the analogous 2-furfurylidene-5,6-dimethyl-6-ethylcyclohexanone (XXI) and 2-furfurylidene-5,6-dimethyl-6-phenylcyclohexanone (XXII). An important difference in the former is the occurrence of a McLafferty rearrangement now possible because of the 6-ethyl substituent. This gives rise to an M − C_2H_4 peak distinguishable from the M − CO peak by high-resolution mass spectrometry and by deuterium labeling of the terminal methyl group in the 6-ethyl substituent (XXIa).

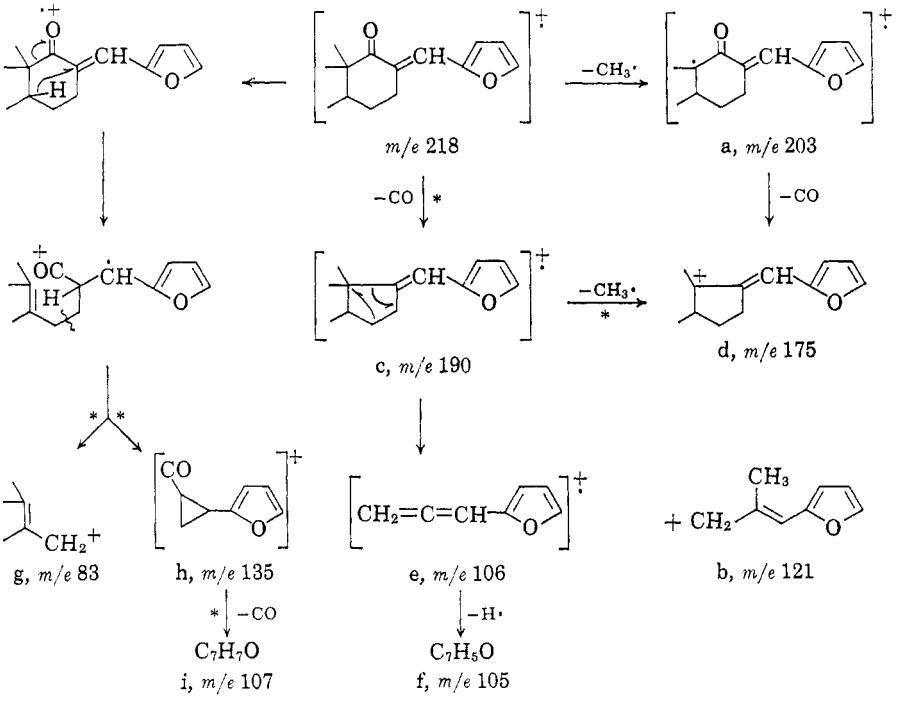
Table IV. Summary of Major Fragment Ions of 2-Furfurylidene-5,6,6-trimethylcyclohexanone (VIII) and Its 6-Methyl-d_3 Derivative (VIIIa)

Compd	M+	*m/e* values for fragment ions a	b	c	d	e	f	g	h	i
 VIII	218	203	121	190	175	106	105	83	135	107
 VIIIa	221	203 206	121 124	193	175 178	106	105	86	135	107

2-Furfurylidene-6,6-dimethylcyclohexanone (VII). The mass spectrum (Figure 4) differs from that (Figure 3) of the trimethyl analog VIII in that the peak at *m/e* 121 is greatly diminished. All other features of the two spectra are quite similar.

1-Benzylidene-2,2,3-trimethylcyclopentane (XXIII). The mass spectrum (Figure 5) resembles closely that (Figure 2) of the related benzylidenehydrindan VI. Again there is a pronounced M − 15 peak, alkyl rear-

Scheme VI. Major Fragmentation Pathways of 2-Furfurylidene-5,6,6-trimethylcyclohexanone (VIII) after Electron Impact



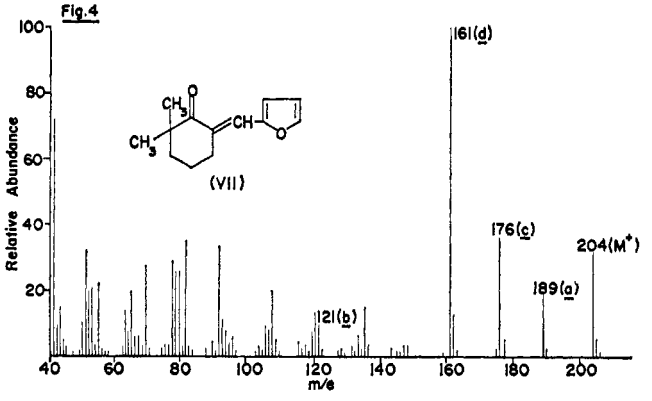


Figure 4. Mass spectrum of 2-furfurylidene-6,6-dimethylcyclohexanone (VII); the ions of mass 189, 176, and 161 are the appropriate analogs of ions a, c, and d in Scheme VI, while ion b (*m/e* 121) is identical with that depicted in Scheme VI.

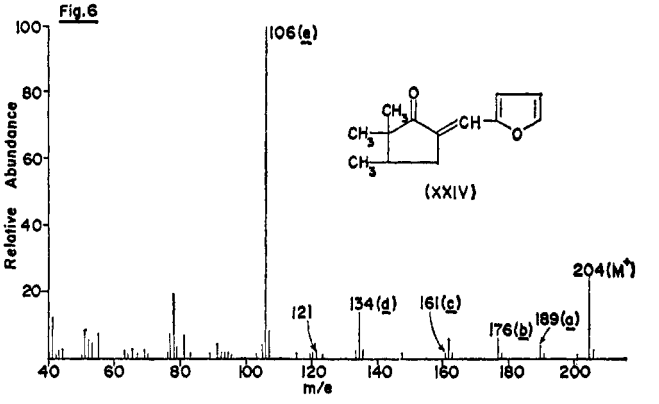


Figure 6. Mass spectrum of 2-furfurylidene-4,5,5-trimethylcyclopentanone (XXIV); see Scheme VII.

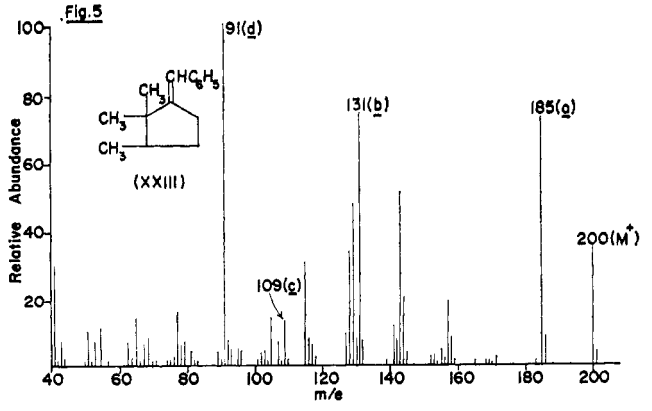
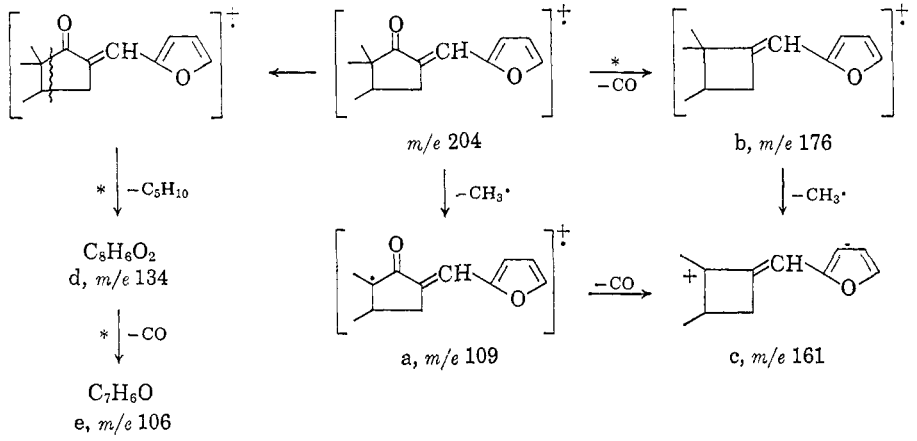


Figure 5. Mass spectrum of 1-benzylidene-2,2,3-trimethylcyclopentane (XXIII); ions b and d are identical with those shown in Scheme V, while the ions of mass 185 and 109 are the appropriate analogs of ions a and c in that scheme.

rangement leads to an intense peak at *m/e* 131, and hydrogen rearrangement followed by cleavage gives the tropylium cation (*m/e* 91) and the cyclopentene cation (*m/e* 109). The latter corresponds to the hydrindene cation c (*m/e* 135) in Scheme V. At 12 ev the only significant fragmentation is loss of a methyl radical.

2-Furfurylidene-4,5,5-trimethylcyclopentanone (XXIV). The mass spectrum (Figure 6) is much simpler than that (Figure 3) of the corresponding cyclohexanone (VIII). It is immediately apparent that the alkyl rearrangement (*m/e* 121) is essentially absent in a five-membered ketone, and this was confirmed by examining the mass spectra of some 16-furfurylidene-17-keto steroids. The principal modes of fragmentation are summarized in Scheme VII. Again loss of carbon monoxide and/or a methyl radical occurs, giving rise to ions a, b, and c. The dominant feature of the spectrum, however, is an intense peak at *m/e* 106. High-resolution mass spectrometry shows that this ion has the composition C_7H_6O, and metastable peaks support its proposed genesis by elimination of trimethylethylene to give d (*m/e* 134) and subsequent loss of carbon monoxide to e. The fragmentation of the furfurylidene-hydrindanone analog XIX is completely analogous and requires no further discussion.

Scheme VII. Major Fragmentation Pathways of 2-Furfurylidene-4,5,5-trimethylcyclopentanone (XXIV) on Electron Impact



Experimental Section[13]

2-Arylidene-1-decalones and 9-Alkyl Derivatives. These compounds (Table I, XII–XVIII) were prepared by condensation of 1-decalone with the appropriate aldehyde and subsequent alkylation with the appropriate alkyl halide.[7] The products were characterized by their mass spectra which showed the appropriate molecular ion in each case.

***trans*-2-Furfurylidene-9-methyl-d_3-1-decalone (IIIa).** *trans*-9-Methyl-d_3-1-decalone[14] (4.5 mg) in 96% ethanol (0.04 ml) was treated with 15% aqueous caustic soda (0.01 ml) and freshly distilled furfuraldehyde (0.005 ml) was added. The reaction mixture was left at room temperature under a nitrogen atmosphere for 6 hr, and the crystalline product was collected. Recrystallization from methanol gave the *furfurylidene derivative* as cream prisms, mp 108–109°.

2-Furfurylidene-5,6,6-trialkylcyclohexanones. 2,3-Dimethylcyclohexanone[8] (2 g) and redistilled furfuraldehyde (1.6 g) were stirred in an atmosphere of nitrogen during the addition of sodium methoxide (0.9 g) in methanol (15 ml). The addition was carried out during 5 min and the temperature was kept below 50°. The mixture was left overnight and poured into water (250 ml), and the solid product was collected and recrystallized from hexane, giving **2-furfurylidene-5,6-dimethylcyclohexanone** as yellow prismatic needles, mp 54.5–55.5°.

Anal. Calcd for $C_{13}H_{16}O_2$: C, 76.44, H, 7.90. Found: C, 76.31; H, 7.93.

The furfurylidenecyclohexanone was alkylated with methyl iodide in *t*-butyl alcohol in the presence of potassium *t*-butoxide following the general procedure of Johnson.[7]

2-Furfurylidene-5,6,6-trimethylcyclohexanone (VIII) was obtained as pale yellow tablets, mp 76–77°.

Anal. Calcd for $C_{14}H_{18}O_2$: mol wt, 218. Found: mol wt (mass spectroscopy), 218.

A similar procedure using methyl-d_3 iodide instead of methyl iodide gave the 6-methyl-d_3 analog (VIIIa), mp 76–77°. Alkylation with ethyl iodide gave **2-furfurylidene-5,6-dimethyl-6-ethylcyclohexanone (XXI)** as an unstable yellow gum which failed to crystallize. It was purified by glpc (5-ft silicone rubber, 200°).

Anal. Calcd for $C_{15}H_{20}O_2$; C, 77.55; H, 8.68. Found: C, 77.71; H, 8.62.

Alkylation with ethyl-β-d_3 bromide gave the corresponding **6-ethyl-β-d_3 analog XXIa.**

***cis*-2-Benzylidene-9-methyl-d_3-1-decalone (Xa) and *cis*-1-Benzylidene-8-methyl-d_3-hydrindan (VIa).** 2-Benzylidene-1-decalone (6 g) was added to a suspension of sodium hydride (0.6 g) in dimethoxyethane (50 ml) and the mixture was stirred under nitrogen at room temperature. Trideuteriomethyl iodide (98% d_3 1.76 ml, 10% excess) was added and the mixture was stirred overnight in a nitrogen atmosphere at room temperature. The mixture was then heated under reflux for 1 hr and poured into water (500 ml), and the product was extracted with ether (two 100-ml portions). The ethereal extracts were combined, washed with water (two 100-ml portions), and dried over anhydrous magnesium sulfate, and the ether was removed. The crude product (5.6 g, 87%) was recrystallized once from methanol to give ***cis*-2-benzylidene-9-methyl-d_3-1-decalone (Xa)** as yellow plates, mp 105–106°. This compound was converted by known procedures[11] into *cis*-8-methyl-d_3-1-hydrindanone, which was shown by glpc (10-ft 10% Carbowax 20M on 60–80 Chromosorb W, 110°) to contain approximately 20% of the corresponding *trans* isomer, arising from *trans* isomer contaminant in the starting material. The Grignard reagent from magnesium (0.155 g, 2 mole equiv) and benzyl chloride (0.82 g, 2 mole equiv) in ether (25 ml) was prepared under nitrogen and stirred during the addition of the above *cis*-8-methyl-d_3-1-hydrindanone (0.5 g, 1 mole equiv) in ether (25 ml). The mixture was refluxed for 4 hr and decomposed with 5% hydrochloric acid (30 ml). The product was extracted into ether, the ether layer was washed and dried over anhydrous magnesium sulfate, and the ether was evaporated. The crude residue was treated with a mixture of pyridine and phosphorus oxychloride (27:18, 25 ml) and left overnight. The reaction mixture was poured onto ice, the product extracted into ether, and the ethereal solution washed with a saturated solution of sodium bicarbonate and dried over anhydrous magnesium sulfate. The ether was removed and the residue purified by glpc (10-ft 10% Apiezon L on 60–80 Chromosorb W, 210°). The following compounds were isolated: (a) 1,2-diphenylethane (identified by comparison of retention times and infrared spectrum with an authentic specimen); (b) ***cis*-1-benzyl-8-methyl-d_3-Δ^1-hydrindene** (identified by its nmr spectrum ($CDCl_3$), which showed a multiplet at δ 3.33, corresponding to the two benzylic protons, and a multiplet at δ 4.99, corresponding to the single olefinic proton at C-2, and its infrared spectrum showing $\nu_{C=C}$ 1610 cm^{-1}); (c) ***cis*-1-benzylidene-8-methyl-d_3-hydrindan** [(VIa, identified by its nmr spectrum ($CDCl_3$) which showed a triplet at δ 6.26 (J = 2.5 cps), corresponding to one benzylic–allylic proton, and a broad multiplet at δ 2.7, corresponding to the two allylic protons at C-2, and its infrared spectrum showing $\nu_{C=C}$ 1650 cm^{-1}]. In addition, small quantities of the *trans* isomers of the last two compounds were also isolated (the latter having arisen from *trans*-hydrindanone impurity in the starting material). The unlabeled hydrindan VI was prepared in an identical fashion starting with X.

In an analogous sequence 2-furfurylidene-5,6,6-trimethylcyclohexanone gave a mixture of **1-benzylidene-4,5,5-trimethylcyclopentane (XXIII)** and **1-benzyl-4,5,5-trimethyl-Δ^1-cyclopentene** which was separated by glpc (5-ft 10% SE 30 on 60–80 Chromosorb W, 185°).

***trans*-2-Furfurylidene-9-methyl-1-decalone-3-d_1 (IIIb) and *trans*-2-Benzylidene-9-methyl-1-decalone-3-d_1 (XIb).**[15] *trans*-1-Methoxy-

(13) Melting points (uncorrected) were determined on the Kofler block. Ultraviolet absorption spectra were measured with a Perkin-Elmer Model 137 infracord spectrophotometer. Mass spectra measured with an Atlas CH-4 mass spectrometer (fitted with a TO-4 ion source equipped with a gas cartridge and maintained at 200°) were run by Drs. J. K. MacLeod and A. M. Duffield. Spectra measured on the AEI MS-9 instrument (using the heated inlet system) were run by Dr. J. K. MacLeod and Mr. R. G. Ross. Spectra measured on the CEC Model 21-103C instrument (200° heated all-glass inlet system) were run by Mr. N. Garcia. Gas–liquid partition chromatography (glpc) was carried out on a Varian Aerograph 202 machine using helium as carrier gas at a flow rate of 150 cc/min. The nmr spectra were measured by Mr. J. H. Freed using a Varian A-60 spectrometer. Microanalyses were performed by Messrs. E. Meier and J. Consul.

(14) E. Lund, H. Budzikiewicz, J. M. Wilson, and C. Djerassi, *J. Am. Chem. Soc.*, **85**, 941 (1963).

(15) Both compounds were synthesized by Dr. A. M. Duffield of this laboratory.

3-keto-9-methyl-$\Delta^{1,6}$-hexahydronaphthalene[12] (0.5 g) was reduced with lithium aluminum deuteride (0.12 g) in ether (40 ml) for 2 hr. Excess reagent was destroyed with a saturated solution of sodium sulfate and the ether-soluble material was heated with water (2.0 ml) and concentrated sulfuric acid (0.3 ml) at 97° for 2.5 hr. The mixture was cooled and the product was extracted into ether and vacuum distilled, yielding ***trans*-1-keto-9-methyl-$\Delta^{2,6}$-hexahydronaphthalene** (0.33 g), bp 65–70° (air-bath temperature) (1 mm), as a yellow oil. This product was dissolved in ethyl acetate (20 ml) and hydrogenated over 10% palladium–carbon catalyst at atmospheric pressure until gas absorption ceased (30 min, 42 cc). The catalyst was removed by filtration, the solvent was evaporated, and the residue was distilled (bath temperature 130–140°) at 18 mm to give ***trans*-9-methyl-1-decalone-3-d_1** (0.32 g). This decalone (0.06 g) in ethanol (0.6 ml) was treated with 15% aqueous sodium hydroxide solution (0.16 ml) and freshly distilled furfuraldehyde (0.04 ml) was added. After standing at room temperature in the dark for 18 hr, the mixture was filtered and the solid product recrystallized from methanol to afford ***trans*-2-furfurylidene-9-methyl-1-decalone-3-d_1 (IIIb)** as cream plates, mp 86–87° (λ_{max} 321 mμ (log ε 4.36, in ethanol)). The **benzylidene derivative (XIa)** was obtained as colorless plates, mp 92.5–93.5°, by using benzaldehyde (0.04 ml) instead of furfuraldehyde in the last step.

2-Furfurylidene-5,6-dimethyl-6-phenylcyclohexanone (XXII). A solution of 4,5-dimethyl-4-phenyl-Δ^2-cyclohexenone[5] (2.48 g) in methanol (20 ml) was treated with 30% hydrogen peroxide (5.15 ml). The mixture was cooled to 15° and 6 *N* caustic soda (1.48 ml) was added dropwise with stirring at 15–17° during 12 min. The mixture was kept at 15–20° for 3 hr, poured into water, and extracted with ether. The ethereal extract was washed and dried over anhydrous magnesium sulfate and the ether evaporated. **4,5-Dimethyl-4-phenylcyclohexanone 2,3-epoxide** was obtained as a colorless oil, ν_{CO} 1710 cm^{-1}. The crude epoxy ketone (2 g) was refluxed with 100% hydrazine hydrate (23 ml) containing hydrazine sulfate (7.4 g) for 20 min. The mixture was cooled, diluted with water, and extracted with ether. The ethereal extract was washed and dried over anhydrous magnesium sulfate, and the ether was removed, leaving a viscous brown gum. Distillation at 0.7 mm (bath temperature 150–170°) gave **5,6-dimethyl-6-phenyl-Δ^2-cyclohexenol** (0.6 g) as a pale yellow viscous oil, a portion of which was purified by glpc (10-ft 10% Apiezon L on 60–80 Chromosorb W, 180°).

Anal. Calcd for $C_{14}H_{18}O$: C, 83.12; H, 8.79. Found: C, 83.0; H, 8.90.

Oxidation of the alcohol with excess 8 *N* Jones reagent[10] in acetone gave after ether extraction **5,6-dimethyl-6-phenyl-Δ^2-cyclohexenone** (0.4 g) as a yellow oil, ν_{CO} 1680 cm^{-1}.

Anal. Calcd for $C_{14}H_{16}O$: C, 83.96: H, 8.05. Found: C, 83.67; H, 8.33.

The cyclohexenone (0.32 g) in ethyl acetate (25 ml) was hydrogenated over 10% palladium–carbon catalyst (100 mg) at room temperature and pressure until hydrogen uptake ceased (47 ml). The catalyst was removed and the solvent evaporated, giving **5,6-dimethyl-6-phenylcyclohexanone** as a colorless oil, ν_{CO} 1725 cm^{-1}. A portion was purified for analysis by glpc (10-ft 10% Apiezon L on 60–80 Chromosorb W, 175°).

Anal. Calcd for $C_{14}H_{18}O$: C, 83.12; H, 8.79. Found: C, 83.17; H, 9.06.

The cyclohexanone (0.25 g) was dissolved in methanol (5 ml) containing sodium methoxide (0.1 g), and redistilled furfuraldehyde (0.15 g) was added. The mixture was left at room temperature under nitrogen overnight and poured into water, and the product was isolated by ether extraction as usual. **2-Furfurylidene-5,6-dimethyl-6-phenylcyclohexanone (XXII)** (0.3 g) was obtained as a yellow viscous gum which did not crystallize and darkened rapidly on exposure to air. Purification was effected by glpc (5-ft 10% SE30 on 60–80 Chromosorb W, 250°).

Anal. Calcd for $C_{19}H_{20}O_2$: C, 81.40; H, 7.19. Found: C, 81.50: H, 7.26.

2-Furfurylidene-4,5,5-trimethylcyclopentanone (XXIV). 2,2,3-Trimethylcyclopentanone (0.126 g) and redistilled furfuraldehyde (0.096 g) were dissolved in methanol (2 ml), and sodium methoxide (0.050 g) was added. The mixture was left overnight under an atmosphere of nitrogen and poured into water, and the product was isolated by ether extraction and purified by glpc (5-ft SF96, 185°). The product was obtained as an unstable yellow oil which darkened immediately on exposure to air.

Anal. Calcd for $C_{13}H_{16}O_2$: mol wt, 204. Found: mol wt (mass spectroscopy), 204.

Similarly *cis*-8-methyl-d_3-hydrindanone (see above) was condensed with furfuraldehyde to give the **furfurylidene derivative (XIX)** as an unstable viscous yellow gum.

Anal. Calcd for $C_{15}H_{15}D_3O_2$: mol wt, 233. Found: mol wt (mass spectroscopy), 233.

Communications to the Editor

A New Route to the Preparation and Configurational Correlation of Optically Active Phosphine Oxides[1]

Sir:

Optically active phosphine oxides occupy a key position in the stereochemical investigations of phosphorus compounds.[2,3] Produced[3] from optically active quaternary phosphonium salts by reaction with sodium hydroxide, from optically active phosphoranes by the Wittig reaction, or from optically active phosphines by oxidation, phosphine oxides are themselves precursors to optically active phosphines by reduction with trichlorosilane.[4] Present synthetic routes to optically active phosphines ($R_1R_2R_3P$) and phosphine oxides ($R_1R_2R_3PO$) require resolution[2] of the individual phosphine oxides or, more commonly,[3] resolution of quaternary phosphonium salts ($R_1R_2R_3R_4P^+X^-$) with subsequent cleavage, either by cathodic reduction or by reaction with base, to effect the elimination of R_4. Consequently, whatever the method of preparation, the ultimate starting material has to be one in which the three groups, R_1, R_2, and R_3, are already present prior to optical resolution. This structural commitment severely restricts the scope of these methods and limits the pathways which are accessible for configurational intercorrelations, particularly so since, to achieve selective elimination, the ease of cleavage of R_4 must be substantially greater than that of the other three groups.

We have developed a synthetic scheme which overcomes these difficulties. Unsymmetrically substituted

(1) This work was supported by the Air Force Office of Scientific Research under Grant No. AF-AFOSR-1188-67.

(2) Resolution of ethylmethylphenylphosphine oxide (**5**) provided the first example of an optically active phosphorus compound (J. Meisenheimer and L. Lichtenstadt, *Ber.*, **44**, 356 (1911); J. Meisenheimer, J. Casper, M. Höring, W. Lauter, L. Lichtenstadt, and W. Samuel, *Ann.*, **449**, 213 (1926)).

(3) For comprehensive reviews giving citations to the original literature, see R. F. Hudson and M. Green, *Angew. Chem. Intern. Ed. Engl.*, **2**, 11 (1963); L. Horner, *Pure Appl. Chem.*, **9**, 225 (1964); W. E. McEwen in "Topics in Phosphorus Chemistry," Vol. 2, M. Grayson and E. J. Griffith, Ed., Interscience Publishers, Inc., New York, N. Y., 1965, Chapter 1; G. Kamai and G. M. Usacheva, *Russ. Chem. Rev.*, **35**, 601 (1966).

(4) L. Horner and W. D. Balzer, *Tetrahedron Letters*, 1157 (1965).