m.p. 155–157°, $\nu_{max}^{CHCl_3}$ 1710, 1635 cm.$^{-1}$; λ_{max}^{EtOH} 248 mμ (4.22), 303 mμ (3.34).

Anal. Calcd. for $C_{22}H_{26}N_2O_5$: C, 66.31; H, 6.58. Found: C, 66.05; H, 6.71.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, STANFORD UNIVERSITY, STANFORD, CALIF.]

Mass Spectrometry in Structural and Stereochemical Problems. XXI.[1] Fragmentation and Hydrogen Transfer Reactions after Electron Impact on β-Decalones[2]

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The mass spectra of a variety of *trans*- and *cis*-β-decalones together with their deuterated analogs have been measured in order to determine the principal fragmentation modes as well as to examine the occurrence of hydrogen transfer reactions. A comparison of the present results with those of the earlier recorded[4] α-decalone mass spectra show very distinct differences, which are of diagnostic value and which are discussed in detail. In contrast to α-decalones, where the stereochemistry of the ring juncture played an important role, both *trans*- and *cis*-β-decalones exhibit very similar mass spectral fragmentation patterns.

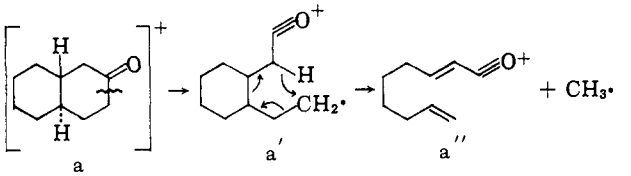
In an earlier paper[4] there was discussed in detail the synthesis and mass spectral fragmentation behavior of a substantial number of deuterated analogs of *trans*- and *cis*-α-decalone, this information being desired as a model for the evaluation of the fragmentation processes observed in polycyclic ketones such as steroids.[5] For this same purpose, it will also be necessary to know the intimate details of the mass spectral fragmentation patterns of β-decalones and of hydrindanones and the present article is concerned with the former group of compounds.

The mass spectra of only two members of this class—*trans*-(I) and *cis*-β-decalone—have been reported in the literature.[6] These measurements were performed with a double-focusing instrument and while no interpretation in terms of fragmentation processes was attempted, the results are nevertheless of considerable importance as the high resolution of the instrument permitted an unequivocal decision regarding the empirical formula of contributing species to a given peak (*e.g.*, *m/e* 55 being made up of $C_4H_7^+$ and $C_3H_3O^+$, while *m/e* 79 consisted only of $C_6H_7^+$ and no $C_5H_3O^+$). As shown below, this information together with observations about the presence or absence of peak shifts upon introduction of labels such as deuterium or methyl offered valuable information about the principal fragmentation modes and hydrogen transfer reactions.

Angularly Unsubstituted β-Decalones

The mass spectra of *trans*- and *cis*-β-decalone are very similar,[6] only slight intensity differences being observed, and our discussion will be limited, therefore, to the spectrum (Fig. 1) of the *trans* isomer I, which will be contrasted with that (Fig. 2) of its 1,1,3,3-d_4-analog II.[7]

Peak M-15 (*m/e* **137 in Fig. 1**).—This fragment is considerably more abundant than in α-decalone[4] and is due to the loss of methyl. In the spectrum (Fig. 2) of the d_4-analog II, this peak shifts to M-18, demonstrating that the CD_3 radical is lost. This observation is readily accommodated by the following mechanism, which involves first the usual[8] cleavage (a) of the C—C=O bond (wavy line) followed by loss of methyl in a six-membered transition state (a′) to pro-



vide the conjugated ion a″. It is interesting to note that this M-15 peak becomes much less pronounced in the mass spectra (Fig. 3 and 4) of the 3-methyl (III) and 1-methyl (V) homologs, and is not shifted to any appreciable extent in the deuterated analogs IV and VI. It cannot be stated unambiguously that instead there is occurring a loss of an ethyl radical, since the unsubstituted β-decalone (I) itself exhibits a significant M-29 peak (Fig. 1).

Peak M-18 (*m/e* **134 in Fig. 1**).—In the α-decalone series, this loss of water has been shown[4] to involve hydrogen atoms from all parts of the molecule. The same statement seems to apply to *trans*-β-decalone (I), where a partial shift to M-19 is noted in the spectrum (Fig. 2) of the d_4-derivative II. Such partial movements to M-19 were also observed in the mass spectra of d_3-3-methyl-(IV) and d_3-1-methyl-(VI) *trans*-decalone-2.

Peak M-29 (*m/e* **123 in Fig. 1**) **and M-28** (*m/e* **138 in Fig. 3 and 4**).—The double-focusing spectrum[6] demonstrates that the M-29 peak is made up of two species, the predominant one being M–C_2H_5 and the remainder (rather insignificant in the *cis* isomer) representing M–CHO. Since this M-29 fragment remains largely M-29 in the spectrum (Fig. 2) of the d_4-analog, the M-29 moiety must be derived from the non-oxygenated ring, an observation which has already been established earlier[4] in the α-decalone series by deuterium labeling in that ring.

An accompanying M-28 peak is relatively small in the β-decalone spectrum (*m/e* 124 in Fig. 1), but this becomes much more important in the spectra (*m/e*

(1) Paper XX, B. Gilbert, J. A. Brissolese, N. Finch, W. I. Taylor, H. Budzikiewicz, J. M. Wilson and C. Djerassi, *J. Am. Chem. Soc.*, **85**, 1523 (1963).

(2) Acknowledgment is made to the National Institutes of Health of the U. S. Public Health Service for financial support (grants No. CRTY-5061 and A-4257).

(3) Taken from part II of the Ph.D. dissertation of E. Lund, Stanford University, 1963. The mass spectra of the various deuterated analogs (*e.g.*, Table I) are reproduced in the thesis.

(4) E. Lund, H. Budzikiewicz, J. M. Wilson and C. Djerassi, *J. Am. Chem. Soc.*, **85**, 441 (1963).

(5) (a) H. Budzikiewicz and C. Djerassi, *ibid.*, **84**, 1430 (1962); (b) C. Djerassi, J. M. Wilson, H. Budzikiewicz and J. W. Chamberlin, *ibid.*, **84**, 4544 (1962); (c) H. Budzikiewicz, J. M. Wilson and C. Djerassi, *Monatsh.*, **93**, 1033 (1962).

(6) J. H. Beynon, R. A. Saunders and A. E. Williams, *Appl. Spectry.*, **14**, 95 (1960).

(7) For reasons which are outlined in our earlier paper (ref. 4), such comparisons with polydeuterated labeled derivatives will often afford only qualitative information. This is of no particular disadvantage, since in our present studies we are only concerned with a discussion of the principal fragmentation processes. Another problem to be considered in quantitative studies is the fact that deuterium in equilibratable positions may partially exchange with the water vapor in the inlet system. Thus when the mass spectrum of α-decalone was measured in an inlet system, which had first been exposed to deuterium oxide vapor, there was observed over 10% of an M + 1 species.

(8) A. G. Sharkey, J. L. Shultz and R. A. Friedel, *Anal. Chem.*, **28**, 934 (1956).

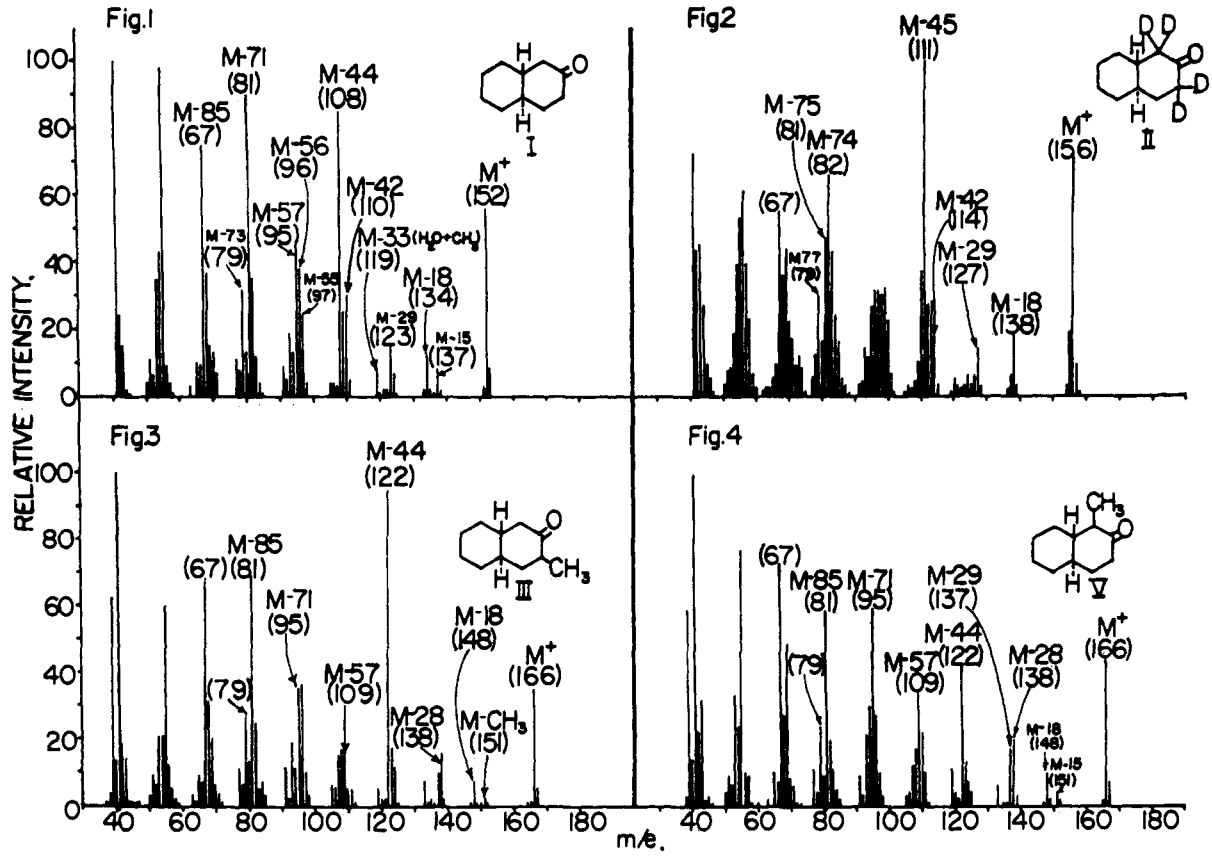
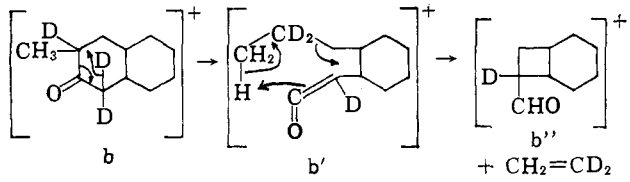


Fig. 1.—Mass spectrum of *trans*-β-decalone (I).
Fig. 2.—Mass spectrum of 1,1,3,3-d_4-*trans*-β-decalone (II).
Fig. 3.—Mass spectrum of *trans*-3-methyldecalone-2 (III).
Fig. 4.—Mass spectrum of *trans*-1-methyldecalone-2 (V).

138 in Fig. 3 and 4) of the methylated homologs III and V. The double-focusing spectrum[6] of I has already demonstrated that the M-28 fragment is due to the loss of ethylene, rather than of carbon monoxide, and the movement of this peak upon deuteration (IV and VI) in the homologous series (III and V) confirms that the same unexpected process operates here also. The shift of the M-28 peak (*m/e* 138 in Fig. 3) to M-30 after deuterium exchange is especially noticeable in the spectra of *trans*-3-methyldecalone-2 (III) and its labeled derivative IV. In order to accommodate the expulsion of ethylene together with one additional hydrogen atom from the other α-position—as indicated by the movement to M-30 upon deuteration—we suggest fission of the 2–3 bond with transfer of the C-1 hydrogen atom (b), followed by back-transfer (b′) of a hydrogen atom from the methyl group to the oxygen-containing fragment, the M-28 species being represented by the cyclobutylaldehyde species b″



The same process could also be visualized for the loss of ethylene in β-decalone (I) itself, except that a cyclopropyl ring would have to be substituted for cyclobutyl in b″.

Peaks M-42 and M-43 (*m/e* 110 and *m/e* 109 in Fig. 1).—These peaks are much weaker than the most characteristic one (M-44) in this region and, furthermore, they both consist[6] of hydrocarbon and oxygen-containing species. Consequently, their movements are difficult to follow in the spectrum (Fig. 2) of the d_4-analog II, but it will be observed that the latter still shows an M-42 peak (*m/e* 114 in Fig. 2), which leads to the conclusion that the $C_7H_{10}O^+$ component of the M-42 fragment (*m/e* 110 in Fig. 1) is due to the loss of C_3H_6 from the non-oxygenated ring. The same observation was made[4] in the α-decalone series, where multiple labeling with deuterium permitted the postulation of a plausible fragmentation mechanism.

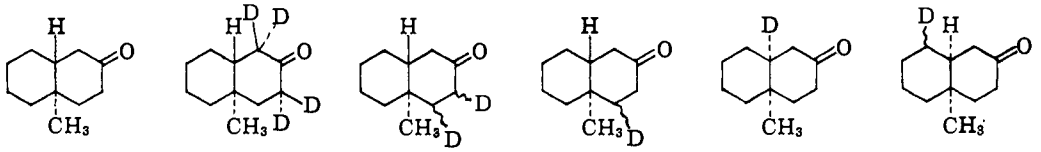
Peak M-44 (*m/e* 108 in Fig. 1).—This peak comprises a single species ($C_8H_{12}^+$). A similar M-44 peak was observed[4] in the α-decalone series, where its genesis could be rationalized mechanistically and shown to be due to the loss of the carbonyl function and its adjacent methylene group, together with a double hydrogen transfer. Such a mechanism cannot be invoked in the β-decalones, and the results (Table I) with labeled analogs of *trans*-10-methyldecalone-2 (VII) demonstrate the existence of a rather complicated rearrangement process, for which no obvious mechanism can be postulated with the information presently in hand.

It should be noted that d_4-*trans*-β-decalone (II) exhibits a shift to M-45 (*m/e* 111 in Fig. 2) demonstrating that in the formation of this ion, one hydrogen atom must have been lost and no less than three hydrogens gained!

The mechanistic situation is completely changed when a methyl group is introduced adjacent to the carbonyl group. While the mass spectra (Fig. 3 and 4) of 3-methyl-(III) and 1-methyl-(V) *trans*-decalone-2 still show an intense M-44 peak (*m/e* 122), their deuterium-labeled analogs IV and VI exhibit M-46 peaks. These observations can be readily accommodated by a mechanism which involves fission of the bond between

TABLE I

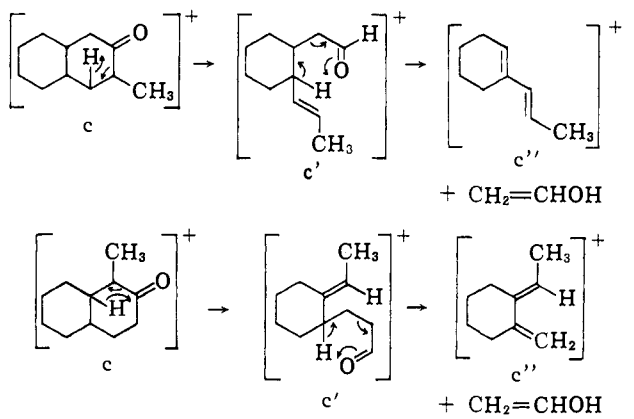
MASS SPECTRA OF 10-METHYLDECALONE-2 AND OF DEUTERATED ANALOGS



Peak (Fig. 5) m/e	VII (166)[a]	VIII[b] (170)[a]	IX (168)[a]	X (167)[a]	XI[18] (167)[a]	XII[c] (167)[a]
151	M-15	15	15	15	15	15
137	M-29	32	31	30	29	29
123	M-43	45	43	43	43	44
122	M-44	45	44	44	44	45
111	M-55	56	56/57	56	55	55
109	M-57	59/60	59	58	57/58	57/58
95	M-71	75	73	72	71/72	71/72
81	M-85	87/88/89	87	86	85/86	85/86

[a] Molecular ion peak. [b] The material contained 17% of the incompletely exchanged d_3-analog. [c] As shown in the Experimental section there is present 23% of the 8,8-d_2-species.

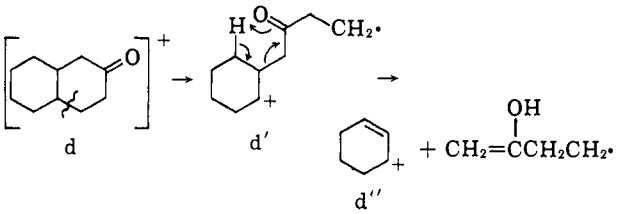
the carbonyl function and the methyl-bearing carbon atom together with transfer of the β-hydrogen (c), followed by a second hydrogen transfer through a six-membered[9] intermediate c′, the final product c″ being a conjugated diene. The mechanism thus becomes completely analogous to that established[4] in the α-decalone series by deuterium labeling in the relevant positions.



Peaks M-55, 56 and 57 (*m/e* 97, 96, 95 in Fig. 1).—Between *m/e* 91 and *m/e* 97 there can be observed (Fig. 1) a series of peaks, of which *m/e* 95, 96 and 97 are the most important ones. A similar group of peaks is noted in the *m/e* 110 region (Fig. 3 and 4) of the methylated homologs III and V. The double-focusing measurements[6] of β-decalone demonstrate that all of these peaks consist of oxygenated and hydrocarbon fragments, and polydeuteration (II, IV, VI) affords a pattern (*e.g.*, Fig. 2) in this mass range, which cannot be used for purposes of elucidating fragmentation mechanisms. In the angularly substituted β-decalones (Table I), M-55 and M-57 become outstanding members of this peak group and are discussed below.

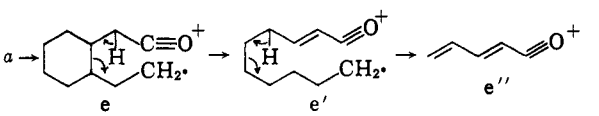
Peak M-71 (*m/e* 81 in Fig. 1).—This peak consists[6] of the ions $C_5H_5O^+$ and $C_6H_9^+$ in a ratio of 4.5/5.5 and upon deuteration (II) remains (see Fig. 2) in part at *m/e* 81 and shifts partly to *m/e* 82. If we assume that it is the hydrocarbon portion of the *m/e* 81 peak which lost all four deuterium atoms, then one can propose the following mechanism (d → d′ → d″) for its genesis, which is in part corroborated by the mass spectra of

(9) Such six-membered intermediates involving hydrogen transfer to a carbonyl oxygen have been postulated first by F. W. McLafferty, *Anal. Chem.*, **31**, 82 (1959). For additional examples and discussion see K. Biemann, "Mass Spectrometry," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp. 119–128.



the deuterated 10-methyldecalone-2 derivatives (Table I).

A plausible explanation for that portion of the *m/e* 81 peak, which suffers migration to *m/e* 82 in the d_4-β-decalone (II) spectrum (Fig. 2), is that we are dealing here with the oxygen-containing moiety. After fission of the bond adjacent to the carbonyl group (a), we propose two hydrogen transfer (e → e′) reactions, which ultimately furnish the stable dienone e″ (*m/e* 81). This mechanism is in agreement with the labeled 10-methyldecalone-2 results (Table I) and the observation that *trans*-1-methyldecalone-2 (V) and its d_3-analog VI both exhibit an intense *m/e* 95 peak (see Fig. 4), which would correspond to species *e″* with the additional methyl group. It should be noted, however, that e″ could also arise from the M-15 ion, a″, although no metastable peak corresponding to this transition could be observed



The *m/e* 81 peak of β-decalone (I) shifts in part also to *m/e* 83 (Fig. 2) upon α-polydeuteration (II). Such a peak movement demands the existence of an additional and more complicated fragmentation process, which is probably also responsible for the existence of the *m/e* 95 peak in the spectrum (Fig. 3) of *trans*-3-methyldecalone-2 (III). That this peak owes its genesis, at least to a large extent, to a process different from that proposed above (e → e′ → e″) for the 1-methyl isomer V (Fig. 4) is demonstrated by the observation that the peak shifts in the spectrum of the d_3-analog IV to a substantial extent to *m/e* 96 and *m/e* 98.

Peak M-73 (*m/e* 79 in Fig. 1–4).—This fragment is represented[6] by $C_6H_7^+$ and remains at *m/e* 79 in the spectra of the methylated (III, V) and deuterated (II, IV, VI) analogs, demonstrating that carbon atoms 1, 2 and 3 cannot be present. Its origin may be due conceivably to further loss of two hydrogen atoms or

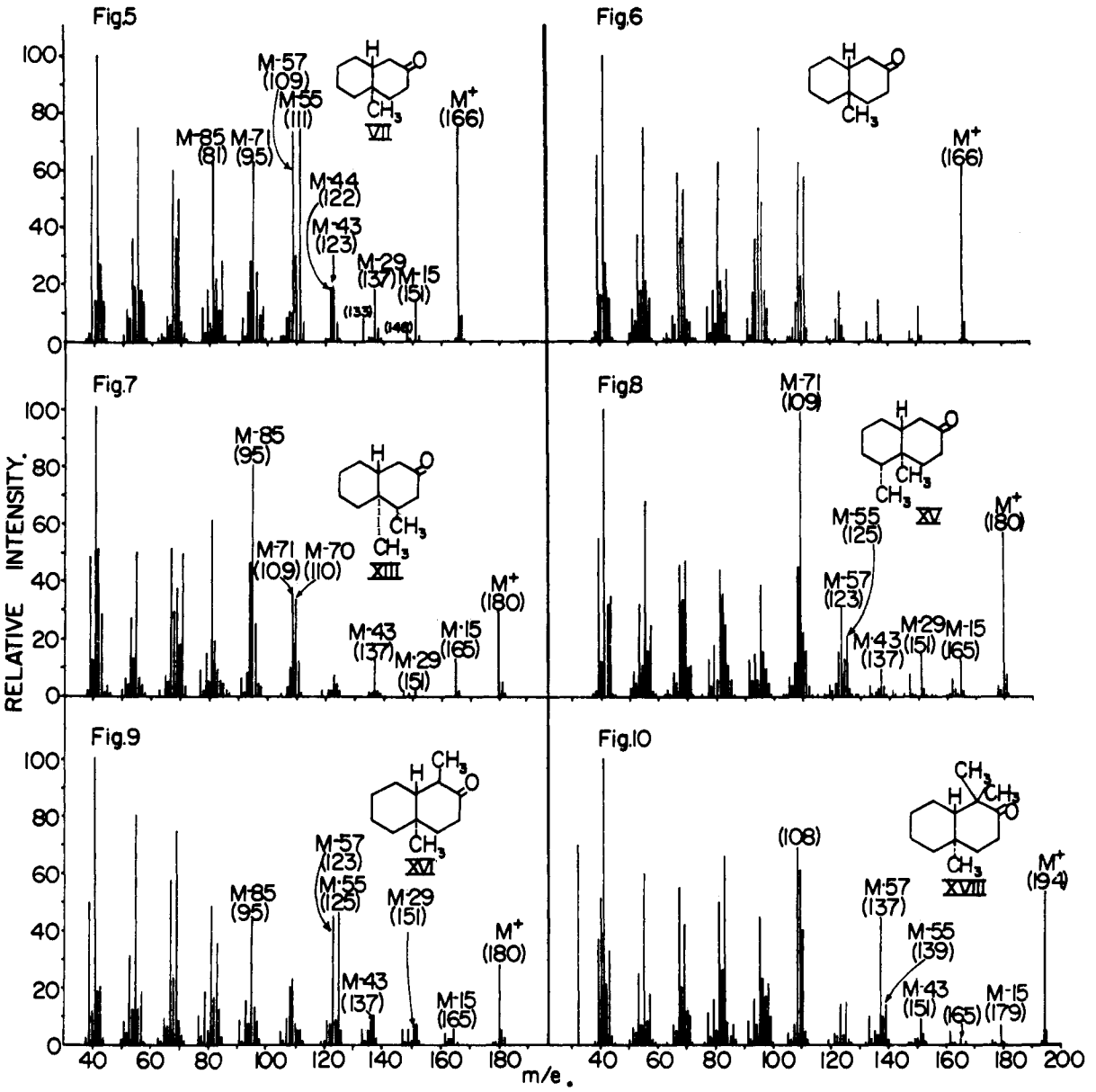


Fig. 5.—Mass spectrum of *trans*-10-methyldecalone-2 (VII).
Fig. 6.—Mass spectrum of *cis*-10-methyldecalone-2.
Fig. 7.—Mass spectrum of *trans*-4,10-dimethyldecalone-2 (XIII).
Fig. 8.—Mass spectrum of *trans*-5,10-dimethyldecalone-2 (XV).
Fig. 9.—Mass spectrum of *trans*-1,10-dimethyldecalone-2 (XVI).
Fig. 10.—Mass spectrum of *trans*-1,1,10-trimethyldecalone-2 (XVIII).

of one hydrogen molecule from d'' (*m/e* 81)—reminiscent of such loss in the mass spectra of hydrocarbons[10]—to produce the cyclohexadienyl cation.

Peak M-85 (*m/e* 67 **in Fig.** 1).—In the α-decalone series, it was shown[4] that this fragment corresponds to $C_5H_7^+$ and that it is derived entirely from the non-oxygenated ring, the hydrogen atoms at positions 2, 3 and 4 not being involved in its formation. While the double-focusing spectrum[6] establishes the $C_5H_7^+$ formulation for the β-decalone spectrum as well, its production must arise, at least in part, by different processes since the spectrum (Fig. 2) of the d_4-analog II indicates a partial shift of this peak to *m/e* 68 and/or *m/e* 69.

Angularly Methylated β-Decalones

As can be noted from a comparison of Fig. 5 and 6, the mass spectra of *trans*- and *cis*-10-methyldecalone-2 are very similar and the discussion of the principal fragmentation processes will be restricted to the *trans* series. Five deuterated analogs have been prepared and the presence or absence of shifts of the principal peaks is summarized in Table I.[3] In addition, there have been examined the mass spectra (Fig. 7–10) of four methylated homologs (XIII, XV, XVI, XVIII) of *trans*-10-methyldecalone-2 and their fragmentation behavior, together with two α-polydeuterated analogs (XIV, XVII), will be discussed where pertinent.

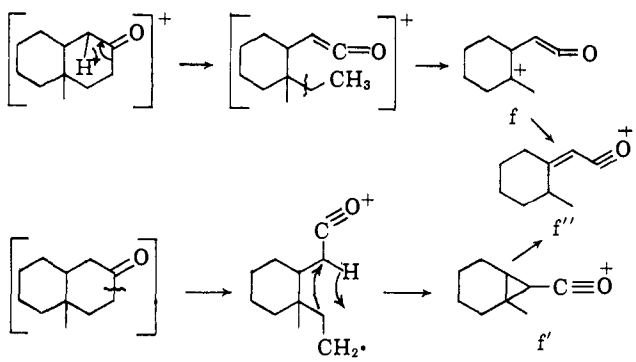
Peak M-15 (*m/e* **151 in Fig. 5**).—In contrast to the angularly unsubstituted β-decalone (I), where this peak is due to loss of an α-carbon atom (see a''), the M-15 fragment in the 10-methyldecalone series is entirely derived from loss of the angular methyl group as demonstrated by the deuterium labeling experiments (Table I). It is not possible, however, to state with the information in hand which of the methyl groups is lost in the polymethylated derivatives XIII–XVIII,

(10) *E.g.*, S. Meyerson and P. N. Rylander, *J. Am. Chem. Soc.*, **79**, 1058 (1957).

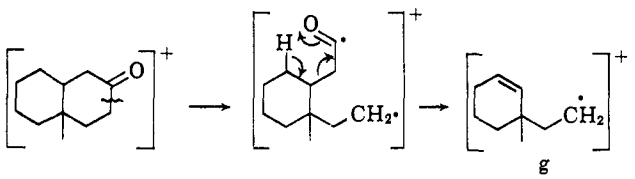
except that the labeled analogs (XIV, XVII) demonstrate again that the α-ring carbon is not involved.

Peak M-18 (*m/e* **148 in Fig. 5**).—This is of negligible significance and its shifts in the deuterated analogs VIII–XII can hardly be followed. More pronounced is the M-33 peak (loss of methyl and water) at *m/e* 133 (Fig. 5); its partial shift to M-34 in the deuterated analogs demonstrates the previously established[4] random loss of hydrogen during the elimination of water.

Peak M-29 (*m/e* **137 in Fig. 5**).—From the shifts of this peak in the mass spectra[3] (Table I) of the deuterated derivatives VIII, IX and X, it can be learned that carbon atoms 3 and 4 are lost together with their attached hydrogen atoms. One additional hydrogen atom must have been transferred to the departing species and C-1 is clearly implicated as shown from a comparison (Table I) of the mass spectra of VIII and IX. The following alternative mechanisms (leading to f, f′ or f″ as plausible representations for the *m/e* 137 ion) account for these results and also explain the greatly reduced intensity of the corresponding peak (*m/e* 165) in the spectrum (Fig. 10) of the 1,1,10-trimethyl homolog XVIII.



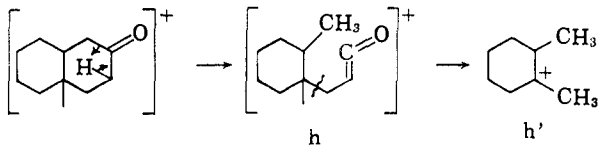
Peak M-43 (*m/e* **123 in Fig. 5**).—The mass spectra of the 3,4-d_2-(IX) and 4-d_1-(X) labeled derivatives show (Table I) that C-3 and C-4 cannot be involved in this fragmentation, while the spectrum of the 1,1,3,3-d_4-analog VIII indicates participation of C-1. Most importantly, the C-8 labeled derivative XII shows that one of the C-8 hydrogens is transferred, an observation which is accommodated readily by the following mechanism leading to g and the *m/e* 123 ion.



The identical mechanism can be applied to explain the appearance of the M–43 peak (*m/e* 137) in the mass spectra (Fig. 7 and 8) of the 4-methyl (XIII) and 5-methyl (XV) homologs, but alternate processes must operate in producing these fragments in the spectra (Fig. 9 and 10) of the 1,10-dimethyl (XVI) and 1,1,10-trimethyl (XVIII) β-decalones. The availability of the d_3-analog XVII of XVI does not shed any light on this point because of the multiplicity of peaks in the range *m/e* 133–138 (Fig. 9).

Peak M-44 (*m/e* **122 in Fig. 5**).—While an M-44 peak is one of the strongest ones in the spectrum (Fig. 1) of *trans*-β-decalone (I), its intensity is greatly reduced upon angular methylation as can be seen from an inspection of Fig. 5–10. As noted in Table I, the loss of one deuterium atom in the spectrum of the 1,1,3,3-d_4-analog VIII implicates C-1, since no deuterium loss is encountered in derivatives (IX, X) labeled at C-3 or C-4. Furthermore, the deuterium atom at C-8 (XII) but not at C-9 (XI) is transferred to the departing uncharged species. Since this M-44 ion is probably formed by the expulsion of the elements of C_2H_4O, one additional hydrogen attached either to position 5, 6 or 7 must be transferred and no reasonable mechanism can be proposed at this time for this unusual fragmentation process.

Peak M-55 (*m/e* **111 in Fig. 5**).—The observed shifts (Table I) upon deuteration indicate the loss of carbon atoms 2, 3 and 4 with hydrogen transfer from C-3 to the remaining ion (note especially VIII, IX and X), so that a species such as h′ can be proposed, the fission of the 1–10 bond (wavy line in h) being promoted by allylic activation.



This peak represents an interesting mechanistic distinction from the α-decalones, where it could be shown[4] that the M-55 ion is entirely due to loss of C_4H_7 from the non-oxygenated ring. Further support for the type of fragmentation exemplified by h → h′ is provided by the mass spectra (Fig. 8, 9 and 10) of the methylated homologs XV, XVI (shifted to M-56 in XVII) and XVIII, while in the 4,10-dimethyl-β-decalone (XIII) spectrum (Fig. 7) this peak is virtually absent in view of the additional methyl group at C-4.[11]

Peak M-57 (*m/e* **109 in Fig. 5**).—This peak is made up of different species, since only partial shifts are noted (Table I) in several of the deuterium-labeled analogs. The spectra of the 3,4-d_2-(IX) and 4-d_1(X) derivatives indicate that carbon atoms 2, 3 and 4 are lost and this conclusion is verified by the presence of a substantial M-57 peak in the mass spectra (Fig. 8–10) of the 5-methyl (XV), 1,1-dimethyl (XVIII)[12] and 1-methyl (XVI) homologs, by the shift to M-59 in the latter's 1,3,3-d_3-analog XVII, and by the virtual absence of such a peak in the spectrum (Fig. 7) of *trans*-1,10-dimethyldecalone-2 (XIII). In order to lose the elements of C_3H_5O, one hydrogen atom must be transferred to this portion and the partial shifts in the mass spectra (Table I) of the deuterated species VIII, XI and XII indicate that this hydrogen originates from several locations with C-1 (M-59 and M-60 equally abundant in VIII) being preferred. Because of the multiplicity of fragmentation paths, it is not profitable to speculate on mechanisms for this cleavage.

Peak M-71 (*m/e* **95 in Fig. 5**).—The loss of 71 mass units arises by expulsion of the entire ring A as can be seen from the mass spectra (Table I) of VIII, IX and X, which are labeled in that ring with deuterium. In *trans*-4,10-dimethyldecalone-2 (XIII) one would expect the loss of 85 rather than 71 mass units due to the additional methyl substituent and the M-85 fragment (*m/e* 95 in Fig. 7) is in fact the second most abundant ion in that spectrum and is shifted to M-89 in the 1,1,-3,3-d_4-analog. A less intense M-71 peak (*m/e* 109 in Fig. 7) in the mass spectrum of XIII must represent an ion that has retained parts of ring A because of the

(11) The presence of an M-69 peak in XIII cannot be established unambiguously on the basis of the anticipated shifts in the labeled analog XIV because of the presence of intense M-70 and M-71 peaks (*m/e* 110 and 109 in Fig. 7).

(12) The very strong *m/e* 108 peak present in the mass spectrum (Fig. 10) of *trans*-1,1,10-trimethyldecalone-2 (XVIII), which is much less intense in all of the other spectra, represents a characteristic feature of such *gem*-dimethyl β-decalones and has also been observed in 4,4-dimethyl-3-keto steroids. Its genesis will be discussed in connection with deuterium labeling experiments currently being performed in the steroid series.

observed shifts (M-73 and M-74) in the spectrum of its d_4-labeled derivative XIV. In accordance with expectation, the mass spectrum (Fig. 9) of the isomeric *trans*-1,10-dimethyldecalone-2 (XVI) contains a substantial M-85 peak (*m/e* 95 in Fig. 9), which is shifted to M-88 in its 1,3,3-d_3-derivative XVII.

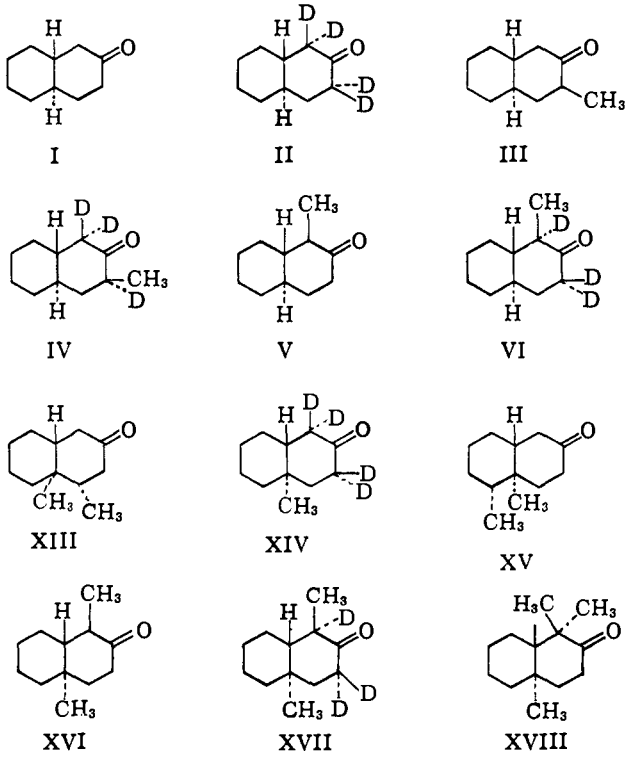
A mechanism as outlined above (d → d′ → d″) for the formation of an M-71 ion in the β-decalone (I) spectrum (Fig. 1) involves the loss of one of the C-8 hydrogens. Such a fragmentation process does indeed take place also with the angularly substituted β-decalones as illustrated in Table I by the appropriate shift upon deuteration at C-8 (XII). However, the approximately equal splitting of this peak in the spectrum (Table I) of 9-d_1-*cis*-10-methyldecalone-2 (XI) between M-71 and M-72 indicates that at least one other fragmentation process is involved in the production of the M-71 ion with participation of the C-9 rather than C-8 hydrogen atom.

Peak M-85 (*m/e* **81 in Fig. 5**).—The earlier results[4] in the α-decalone series demonstrated that this ion arose from ring B with accompanying extensive hydrogen scattering. The shifts (Table I) of this peak in the deuterated analogs of 10-methyl-β-decalone show that the same situation obtains, at least in part, also in this group.

A portion of this peak is probably made up of the *m/e* 81 ion e″, since there occurs a substantial shift (Table I) of this peak to *m/e* 82 in XI and XII, but not in IX and X. The d_4-analog VIII is the only one in which a partial movement to *m/e* 83 is observed, all of which is in accordance with the e → e′ → e″ mechanism proposed above for the M-71 peak in the β-decalone spectrum (Fig. 1).

Stereochemical Considerations and General Conclusions

As noted above, the effect of stereoisomerism at the ring juncture upon the mass spectra of isomeric β-decalones is much less pronounced than in the α-decalone series,[4] only relatively minor intensity differences being observed. This apparent discrepancy can be rationalized by the assumption that in α-decalones, the cleavage of the most labilized bond, connecting the carbonyl group and a tertiary or quaternary carbon atom, is governed by the energy gain caused by the release of strain between the two rings. In β-decalones, however, fission of such a bond is not possible and other fragmentations adjacent to the carbonyl group prevail which are less affected by differences in a *cis* or *trans* ring juncture.



Another contrast between the α- and β-decalones is that the fragmentation and hydrogen transfer processes are much less specific among the latter as compared to the α-decalones,[4] where the carbonyl group is situated spatially much closer to specific hydrogen atoms in the adjacent ring, whose involvement in rearrangements could be demonstrated[4] by deuterium labeling. These observations offer the necessary background for a detailed examination of the mass spectra of ring-A oxygenated steroids (and their deuterated analogs)—now in progress in our laboratory—and where preliminary measurements[5a] have already demonstrated a substantial difference in the fragmentation behavior of 2- and 3-keto steroids as compared to their 1- or 4-keto isomers.

Experimental[13]

3,4-d_2-(IX) and 4-d_1-*trans*-10-Methyldecalone-2 (X).—A freshly distilled sample (200 mg.) of Δ³-*trans*-10-methyloctalone-2[14] (homogeneous by gas phase chromatography using a 5% diethylene glycol succinate column at 185°) was reduced for 15 min. at room temperature and atmospheric pressure with deuterium in cyclohexane solution in the presence of 5% palladium–charcoal catalyst. The catalyst was removed by filtration, the solvent evaporated and the residue distilled to afford the saturated ketone IX, which by mass spectrometry was shown to contain 11% d_0, 38% d_1, 44% d_2 (IX) and 7% d_3 species.

The above material (90 mg.) was heated at 65° for 10 min. with 2 cc. of methanol and 0.5 cc. of 2 *N* sodium hydroxide solution in order to remove any exchangeable deuterium. The equilibrated substance was isolated by ether extraction and after distillation was shown by mass spectrometry to contain 20% d_0, 76% d_1 (X) and 4% d_2 species.

9-d_1-*cis*-10-Methyldecalone-2 (XI).[15]—The catalytic deuteration of Δ¹⁽⁹⁾-10-methyloctalone-2 was performed exactly as described above except that degassed 5% palladium–charcoal catalyst (heated for 5 hr. at 100° (0.1 mm.)) was used. The mass spectrum of the distilled reduction product showed the presence of 8% d_0, 31% d_1, 48% d_2 and 13% d_3 species. After equilibration with sodium hydroxide and distillation, the decalone was shown by mass spectrometry to consist of 15% d_0, 70% d_1 (XI), 11% d_2 and 4% d_3 species.

8-d_1-(XII) and 8,8-d_2-*cis*-10-methyldecalone-2 (XII).[16]—A specimen of Δ¹⁽⁹⁾-10-methyloctalone-2 was equilibrated twice in dioxane–deuterium oxide by the procedure outlined below to provide, after distillation, gas phase chromatographically pure material ($\lambda_{max}^{CHCl_3}$ 6.0 and 6.21 μ), which was shown by mass spectrometry to contain 8% d_2, 18% d_3, 54% d_4, 18% d_5 and 2% d_6 components. After catalytic hydrogenation in cyclohexane solution with 5% palladium–charcoal catalyst, the hydrogenation product contained 8% d_1, 9% d_2, 24% d_3, 50% d_4 and 9% d_5 species. This decalone was now equilibrated by heating for 15 min. at 90° in a current of nitrogen with 2 cc. of dioxane and 2 cc. of 2 *N* sodium hydroxide solution to yield, after distillation, a fraction which by mass spectrometry corresponded to 16% d_0, 57% d_1 (XII), 23% d_2 and 4% d_3 species.

General Procedure for Deuterium Exchange.—In order to obviate the use of the relatively expensive deuteriomethanol, the following exchange procedure was employed to introduce deuterium into the α-positions of the various ketones. The reagent was prepared by adding 50 mg. of clean sodium to 4 cc. of a 1:1 mixture of dry, peroxide-free dioxane and deuterium oxide. Approximately 10 mg. of the ketone and 1 cc. of reagent were heated

(13) All mass spectra were determined with a Consolidated Electrodynamics Corp. mass spectrometer No. 21-103C using an all-glass inlet system heated to 200°, while the isatron temperature was maintained at 270°. The ionizing voltage was kept at 70 e.v. and the ionizing current at 50 μa. Several of the decalones were kindly provided by Prof. W. G. Dauben (University of California) and Prof. G. Stork (Columbia University).

(14) C. Djerassi and D. Marshall, *J. Am. Chem. Soc.*, **80**, 3986 (1958).

(15) The predominance (80%) of the *cis* isomer in the catalytic hydrogenation of Δ¹⁽⁹⁾-10-methyloctalone-2 has been demonstrated by F. Sondheimer and D. Rosenthal, *ibid.*, **80**, 3995 (1958). In view of the similarity of the mass spectra (Fig. 5 and 6) of the *trans*- and *cis*-10-methyldecalone-2, no attempt was made to remove the *trans*-decalone component.

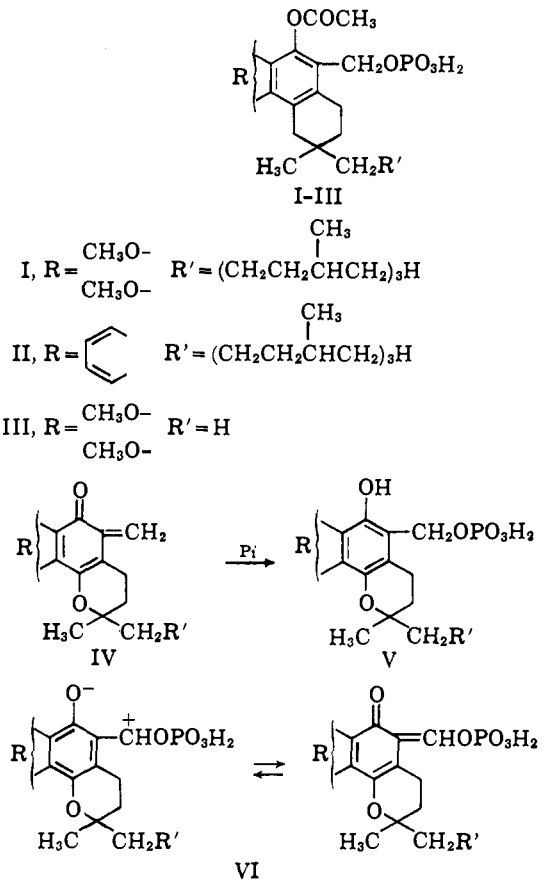
at 70° (heating above 80° caused separation into three phases) for 15 min. in a current of nitrogen, the dioxane distilled under reduced pressure and the product isolated by extraction with ether. A single such treatment usually sufficed to effect at least 80% exchange of the hydrogen atoms adjacent to the carbonyl group.

COMMUNICATIONS TO THE EDITOR

COENZYME Q. XLVII. NEW 5-PHOSPHOMETHYL-6-CHROMANYL DERIVATIVES FROM A NOVEL REACTION OF INTEREST IN OXIDATIVE PHOSPHORYLATION

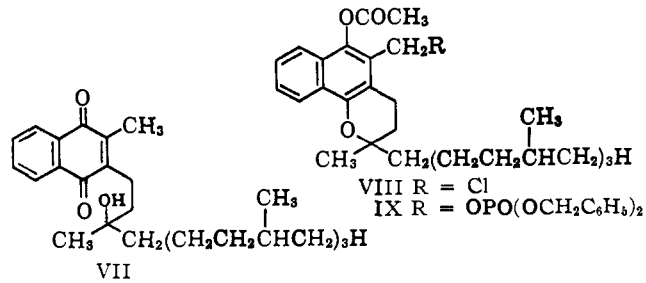
Sir:

The new 5-phosphomethyl derivatives I, II and III of the coenzyme Q and vitamin K groups, which are of current interest in biological oxidative phosphorylation, have been synthesized by a series of steps including a novel cyclization reaction. In view of current concepts,[1] this new structural type of phosphate is more significant than the types related to the monophosphate of dihydrocoenzyme Q_{10}[2] and the 6-chromanyl phosphate of vitamin $K_{1(20)}$.[3] We have considered[1] that the 5-phosphomethyl-6-chromanol type (V) may be enzymically converted by oxidation to the system VI, which would participate in oxidative phosphorylation by generating metaphosphate. The role of metaphosphate has been considered by Todd and co-workers,[4] and an ancillary role for the 5-methyl group has been considered by Chmielewska.[5] The biosynthesis of V may occur[1] by addition of P*i* to the quinone methine IV formed by direct cyclization of the parent 1,4-quinone. The recent interesting paper by Vilkas and Lederer[6] which proposes, on theoretical grounds, addition of P*i* to a quinone methine in the biosynthesis of quinol monophosphates prompts us to report our data in support of such a step in a different mechanism.[1]



Several approaches to these 5-phosphomethyl derivatives were explored and the 5-phosphomethyl-6-chromanyl acetates of the desired 5-phosphomethyl-6-chromanols have been synthesized. As an example, syntheses involving corresponding 5-chloromethyl-6-chromanyl acetates are as follows.

The reaction of vitamin $K_{1(20)}$ and sulfuric acid gave the γ-hydroxyquinone VII; $\lambda_{max}^{isooctane}$ 325 mμ ($E_{1\,cm.}^{1\%}$ 58), 273 mμ ($E_{1\,cm.}^{1\%}$ 375), 264 mμ ($E_{1\,cm.}^{1\%}$ 366), 249 mμ ($E_{1\,cm.}^{1\%}$ 398), 244 mμ ($E_{1\,cm.}^{1\%}$ 380); λ_{max}^{neat} 2.9 μ, 6.0 μ; *Anal.* Found: C, 79.14; H, 10.37. The reaction of VII with acetyl chloride gave the 5-chloromethyl-6-chromanyl acetate VIII: $\lambda_{max}^{isooctane}$ 248 mμ ($E_{1\,cm.}^{1\%}$ 707); λ_{max}^{neat} 5.65 μ; *Anal.* Found: C, 74.82; H, 9.59; Cl, 6.26. The n.m.r. spectrum exhibited absorption at 5.45 τ attributed to Ar–CH_2–Cl and no absorption at 7.92 τ characteristic of the Ar–CH_3 group. The reaction of VIII with silver dibenzylphosphate gave the corresponding phosphate triester IX; $\lambda_{max}^{ethanol}$ 247 mμ ($E_{1\,cm.}^{1\%}$ 497); λ_{max}^{neat} 2.9–4.0 μ, 5.65 μ, 8.3–9.1 μ, 9.5–10.1 μ, 14.4 μ; *Anal.* Found: C, 73.01; H, 8.09; P, 3.84. The n.m.r. spectrum exhibited absorption at 5.05 and 5.20 τ characteristic of the Ar–CH_2–O function. Selective cleavage of the benzyl moieties of the phosphate triester IX yielded the 5-phosphomethyl-6-chromanyl acetate II; $\lambda_{max}^{CCl_4}$ 2.9–4.0 μ, 5.65 μ, 8.3–9.1 μ, 9.5–10.0 μ; $\lambda_{max}^{isooctane}$ 247 mμ ($E_{1\,cm.}^{1\%}$ 506); *Anal.* Found: C, 67.54; H, 8.49; P, 5.00.



The reaction of the 6-chromanol of hexahydrocoenzyme Q_4 with ferric chloride gave the γ-hydroxyquinone X: $\lambda_{max}^{isooctane}$ 276 mμ ($E_{1\,cm.}^{1\%}$ 325); λ_{max}^{neat} 2.80 μ, 6.06 μ, 6.21 μ, 7.90 μ, 8.30 μ, 8.63 μ; *Anal.* Found: C, 72.36; H, 10.44. The reaction of X with acetyl chloride gave the 5-chloromethyl-6-chromanyl acetate XI: $\lambda_{max}^{isooctane}$ 293 mμ ($E_{1\,cm.}^{1\%}$ 48); λ_{max}^{neat} 5.64 μ, 6.30 μ, 8.30 μ, 8.99 μ; *Anal.* Found: C, 68.80; H, 9.43; Cl, 6.73. The reaction of XI with silver dibenzylphosphate gave the corresponding phosphate triester XII: $\lambda_{max}^{isooctane}$ 290 mμ ($E_{1\,cm.}^{1\%}$ 34); λ_{max}^{neat} 5.64 μ, 6.30 μ, 8.30 μ, 8.99 μ, 9.9–

(1) R. E. Erickson, A. F. Wagner and K. Folkers, *J. Am. Chem. Soc.*, **85**, 1535 (1963).

(2) C. H. Shunk, J. F. McPherson and K. Folkers, *Biochem. Biophys. Res. Commun.*, **6**, 124 (1961).

(3) A. F. Wagner, P. E. Wittreich, B. Arison, N. R. Trenner and K. Folkers, *J. Am. Chem. Soc.*, **85**, 1178 (1963).

(4) V. M. Clark, D. W. Hutchinson, G. W. Kirby and A. Todd, *J. Chem. Soc.*, 715 (1961); V. M. Clark, D. W. Hutchinson and A. Todd, *ibid.*, 722 (1961); V. M. Clark and A. Todd, "Quinones In Electron Transport," J. & A. Churchill, Ltd., London, 1961, pp. 190–200.

(5) I. Chmielewska, *Biochem. Biophys. Acta*, **39**, 170 (1960).

(6) M. Vilkas and E. Lederer, *Experientia*, **18**, 546 (1962).