

purified by high-vacuum distillation; mol. wt. (mass spectrum), 415; calcd. for  $C_{29}H_{53}N$ , 415.

*7 $\beta$ -Dimethylaminocholestane (VI)*. The hydrochloride salt of VI was prepared as described by Bird and Cookson.<sup>8</sup> Regeneration of the free base and crystallization of this material from methanol-ether gave VI, m.p. 85–86°; mol. wt. (mass spectrum), 415; calcd. for  $C_{29}H_{53}N$ , 415.

*5 $\alpha$ -Androstan-11-one Oxime*. 5 $\alpha$ -Androstan-11-one<sup>12</sup> (0.20 g.) and hydroxylamine hydrochloride (0.20 g.) were dissolved in 80% aqueous pyridine (20 ml.) and the mixture was heated under reflux for 20 hr.<sup>21</sup> Pyridine was then removed under vacuum and water and ether were added to the residue. The ether phase was washed with water, dried, and evaporated giving an oil (0.20 g.) which crystallized on standing. Recrystallization of this material from acetone gave the crude oxime, m.p. 55–57°, which was reduced without further purification.

*11 $\beta$ -Amino-5 $\alpha$ -androstande*. The oxime (0.15 g.) from above and platinum oxide (50 mg.) in acetic acid (12 ml.) were stirred under 1 atm. of hydrogen at 60° for 3 hr. The product, isolated in the usual manner, was crystallized from acetone at –30° giving 11 $\beta$ -amino-5 $\alpha$ -androstande (0.13 g.), m.p. 103–104°. Attempts to dimethylate this amine by means of formaldehyde and formic acid were unsuccessful, which is consistent with the  $\beta$ -orientation of the amino group.

*Anal.* Calcd. for  $C_{19}H_{33}N$ : C, 82.84; H, 12.08. Found: C, 82.50; H, 12.01.

*11 $\alpha$ -Dimethylamino-5 $\alpha$ -androstande (VII)*. 5 $\alpha$ -Androstan-11-one oxime (0.10 g.) was dissolved in *n*-propyl alcohol (25 ml.) and small pieces of sodium were added to the solution until it became saturated with sodium propoxide. The crude amine was isolated in the conventional manner and then taken up in dry ether. Dry hydrogen chloride was bubbled through the ether solu-

(21) E. B. Hershberg, E. P. Oliveto, and R. Rausser, *Chem. Ind.* (London), 1477 (1958).

tion for a few minutes and the solution was then evaporated to dryness. Hexane was added to the residue and the insoluble salt was isolated by filtration. The salt was shaken with 10% potassium hydroxide and ether. The ether phase was washed with water, dried, and evaporated, and the residue (80 mg.) was chromatographed on alumina (10 g., activity 1). Elution with ether gave traces of 11 $\beta$ -amino-5 $\alpha$ -androstande, m.p. 102–103°, undepressed on admixture with the amine obtained by catalytic reduction of the 11-oxime as described above. Further elution with chloroform and then methanol gave 11 $\alpha$ -amino-5 $\alpha$ -androstande (72 mg.) as an oil. Dimethylation of this material furnished 11 $\alpha$ -dimethylamino-5 $\alpha$ -androstande (VII, 65 mg.), m.p. 66–68° (from acetone); mol. wt. (mass spectrum), 303; calcd. for  $C_{21}H_{37}N$ , 303. The  $\alpha$ -configuration follows from the known<sup>8</sup> stereochemical course of the sodium-alcohol reduction of steroid oximes and the ease of dimethylation as compared with that of the above-described 11 $\beta$ -amine.

*5 $\alpha$ -Androstan-16-one Oxime*. 5 $\alpha$ -Androstan-16-one was converted to the oxime by the standard procedure previously outlined. The oxime had m.p. 198.5–199.5°.

*Anal.* Calcd. for  $C_{19}H_{31}NO$ : N, 4.84. Found: N, 4.89.

*16 $\xi$ -Dimethylamino-5 $\alpha$ -androstande (VIII)*. The above oxime was reduced with lithium aluminum hydride in ether and dimethylated with formic acid and formaldehyde giving, after crystallization of the product from acetone, crystals of VIII, m.p. 77–82°; mol. wt. (mass spectrum), 303; calcd. for  $C_{21}H_{37}N$ , 303.

*17 $\beta$ -Dimethylamino-5 $\alpha$ -androstande (IX)*. 17 $\beta$ -Amino-5 $\alpha$ -androstande<sup>22</sup> was dimethylated by the formic acid-formaldehyde procedure furnishing IX, m.p. 101.5–103° (after crystallization from acetone, lit.<sup>23</sup> m.p. 97–98.5°); mol. wt. (mass spectrum), 303,  $[\alpha]_D^{20}$  (c 1.0,  $CHCl_3$ ).

(22) C. W. Shoppee and J. C. P. Sly, *J. Chem. Soc.*, 345 (1959).

(23) J. C. Babcock, U. S. Patent No. 3009925 (November 1961).

## Mass Spectrometry in Structural and Stereochemical Problems. LXII. Fragmentation and Hydrogen Transfer Reactions of $\beta$ -Hydrindanones. Synthesis of Deuterated $\beta$ -Hydrindanones

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*The mass spectra of trans-8-methylhydrindan-2-one and analogs deuterated in every ring position have been determined. With the aid of high-resolution measurements, it has been possible to determine the major fragmentation modes and to gain insight into the mechanisms by which these processes occur. The mechanisms leading to the formation of fragment ions as well as the syntheses of deuterated derivatives are discussed.*

(1) Paper LXI: H. Brockmann, Jr., H. Budzikiewicz, C. Djerassi, H. Brockmann, and J. Niemeyer, *Ber.*, in press.

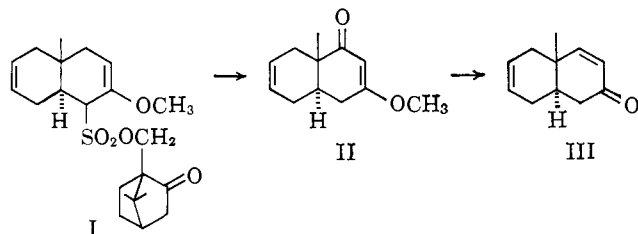
The mass spectrometric fragmentation patterns of  $\alpha$ - and  $\beta$ -decalones have been reported in earlier papers,<sup>2a,b</sup> with the intention of correlating their breakdown processes with those found in polycyclic ketones such as steroids.<sup>3</sup> The decalone system is structurally related to the A–B rings of steroids and, in the same manner,  $\beta$ -hydrindanones may be considered

(2) (a) E. Lund, H. Budzikiewicz, J. M. Wilson, and C. Djerassi, *J. Am. Chem. Soc.*, **85**, 941 (1963); (b) E. Lund, H. Budzikiewicz, J. M. Wilson, and C. Djerassi, *ibid.*, **85**, 1528 (1963).

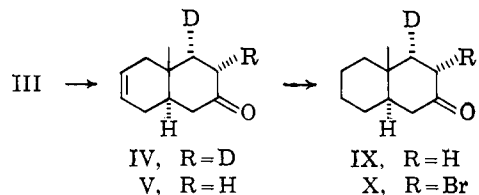
(3) H. Budzikiewicz and C. Djerassi, *ibid.*, **84**, 1430 (1962).

"simple analogs" of 16-keto steroids.<sup>4</sup> With this in mind, the synthesis of  $\beta$ -hydrindanones, deuterated in every ring position, was undertaken in order to study the mass spectrometric fragmentation patterns and hydrogen transfer reactions incident upon electron impact.

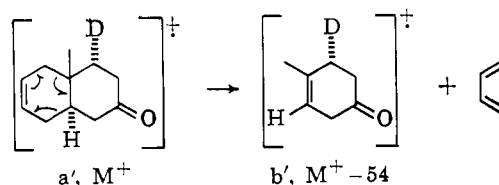
**Synthesis of Deuterated  $\beta$ -Hydrindanones.**<sup>5</sup> The dextrorotatory camphor sulfonate I<sup>6</sup> served as starting material for the synthesis of all nine deuterated  $\beta$ -hydrindanones as well as for the nondeuterated parent substance. Conversion of I to the enol ether II and subsequent transformation to the hexalone III was accomplished according to the literature directions.<sup>7</sup>



Catalytic deuteration of the hexalone III with 2% Pd-CaCO<sub>3</sub> in cyclohexane yielded the desired dideuterio compound IV as the major product, but extensive deuterium scrambling occurred since the mass spectrum of the product showed small amounts of contaminants up to a *d*<sub>7</sub> species. Octalone IV was then converted to the monodeuterated species V by treatment with alkaline methanol. The mass spectrum of this product still exhibited impurities ranging up to a hexadeuterated species.



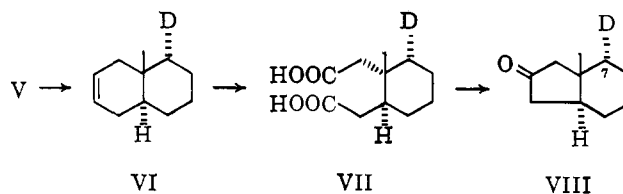
That some random exchange of hydrogen by deuterium<sup>8</sup> had occurred rather than reduction of the isolated double bond during catalytic deuteration is substantiated by the mass spectra of IV and especially of V. Cyclic olefins exhibit a typical reverse Diels-Alder reaction upon electron impact to give a diene and another olefin.<sup>9</sup> In the case of olefin V this may be represented as a'  $\rightarrow$  b'.<sup>10</sup> The mass spectrum of V



exhibits a very intense peak at  $m/e = 111$  ( $M - 54$ ), demonstrating that the isolated double bond remained intact during catalytic deuteration. That the angular methyl group was devoid of scrambling may be noted from the  $M - 15$  region which contains an isotopic impurity pattern similar to that observed in the molecular ion region. The fact that the back-exchanged product V still contained *d*<sub>6</sub> contaminants leads to the conclusion that scrambling occurred predominantly in the nonketonic ring. This is confirmed by noting that the  $M - 54$  region exhibits isotopic contamination (relative to the nondeuterated species) that is considerably smaller than that in the molecular ion region.

The stereochemistry at C-4 in compound V was established by catalytic hydrogenation to the  $\beta$ -decalone IX, followed by bromination with bromine in acetic acid to the bromo ketone X.<sup>11</sup> The nuclear magnetic resonance spectrum of X exhibited a doublet centered at  $\delta$  4.69 and 4.80 with a coupling constant of 5.8 c.p.s., indicative of an axial-equatorial relationship of the hydrogens attached to C-3 and C-4.<sup>12</sup> Hence the configuration of the deuterium atom at C-4 is as shown in structure V.

Huang-Minlon<sup>13</sup> reduction of V afforded the octalin VI, which was oxidized with potassium permanganate-sodium metaperiodate<sup>14</sup> to the crystalline methylcyclohexane-1,2-diacetic-6 $\alpha$ -*d*<sub>1</sub> acid (VII). Pyrolysis of the diacid,<sup>15</sup> using a catalytic amount of barium hydroxide, resulted in the formation of the *trans*-8-methylhydrindan-2-one-7 $\alpha$ -*d*<sub>1</sub> (VIII). (The isotopic purities of deuterated *trans*-8-methylhydrindan-2-ones are listed in Table I.)



Catalytic hydrogenation of the hexalone III in alkaline ethanol, using 2% Pd-CaCO<sub>3</sub> as catalyst, resulted in selective reduction to the octalone XI.<sup>16</sup> This was then reduced with lithium aluminum deuteride to the octalol XII. Tosylation afforded XIII, which when reduced with lithium aluminum hydride afforded in moderate yield<sup>17</sup> the desired monodeuteriooctalin XIV. Oxi-

(4) For a mass spectrometric study of 16-keto steroids see C. Beard, J. M. Wilson, H. Budzikiewicz, and C. Djerassi, *J. Am. Chem. Soc.*, **86**, 269 (1964).

(5) All compounds described are optically active. This will not be considered in the synthesis or discussion since it bears no relevance to the problem, but all structural representations are in accord with the correct absolute configurations.

(6) We are deeply indebted to Dr. W. S. Knowles (Monsanto Chemical Co.) for a generous gift of this material.

(7) A. J. Speziale, J. A. Stephens, and Q. E. Thompson, *J. Am. Chem. Soc.*, **76**, 5011 (1954).

(8) For other examples of deuterium scrambling see (a) K. Biemann, "Mass Spectrometry," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp. 229, 241, and 243; (b) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Structure Elucidation of Natural Products by Mass Spectrometry," Vol. I, Holden-Day Inc., San Francisco, Calif., 1964, Chapter 2.

(9) K. Biemann, *Angew. Chem.*, **74**, 102 (1962). See also H. Ziffer and U. Weiss, *J. Org. Chem.*, **27**, 2694 (1962).

(10) A fishhook ( $\curvearrowright$ ) is used to designate the shift of a single electron, while the movement of an electron pair is signified by an arrow ( $\curvearrowleft$ ): H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Structure Elucidation of Natural Products by Mass Spectrometry," Vol. II, Holden-Day Inc., San Francisco, Calif., 1964, pp. 1-3.

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

(12) F. J. Schmitz and W. S. Johnson, *Tetrahedron Letters*, 647 (1962); H. J. Ringold, M. Gut, M. Hayano, and A. Turner, *Tetrahedron Letters*, 835 (1962).

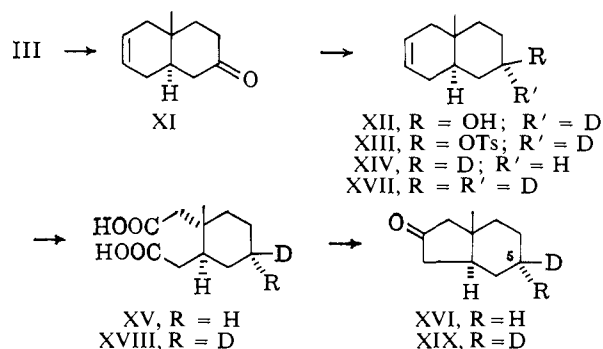
(13) Huang-Minlon, *J. Am. Chem. Soc.*, **68**, 2487 (1946).

(14) J. T. Edwards, D. Holder, W. H. Lunn, and I. Puskas, *Can. J. Chem.*, **39**, 599 (1961).

(15) C. Djerassi, R. Riniker, and B. Riniker, *J. Am. Chem. Soc.*, **78**, 6362 (1956).

(16) L. H. Zalkow, F. X. Markley, and C. Djerassi, *ibid.*, **82**, 6354 (1960).

(17) The major product being the parent alcohol XII. See, for example, H. Schmid and P. Karrer, *Helv. Chim. Acta*, **32**, 1371 (1949), and D. H. R. Barton and C. J. W. Brooks, *J. Chem. Soc.*, 257 (1951).



dation to the diacid XV and pyrolysis to *trans*-8-methylhydrindan-2-one-5 $\beta$ - $d_1$  (XVI) was performed as described above.

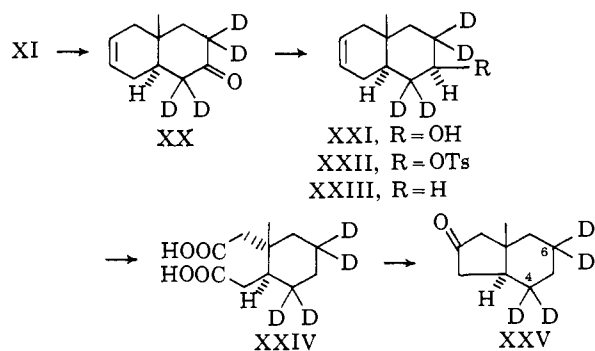
**Table I.** Isotopic Purity of Deuterated *trans*-8-Methylhydrindan-2-ones<sup>a</sup>

Compd.	Purity, %					
	$d_0$	$d_1$	$d_2$	$d_3$	$d_4$	$d_5$
7 $\alpha$ - $d_1$ (VIII)	16	61	20	3		
7 $\beta$ - $d_1$ (XLVI)	4	94	2			
5 $\beta$ - $d_1$ (XVI)	4	94	2			
5,5- $d_2$ (XIX)	5	5	83	7		
4,4,6,6- $d_4$ (XXV)				15	83	2
1,1,3,3- $d_4$ (XXIX)				8	92	
1- $d_1$ (XXXII)	23	57	14	6		
9- $d_1$ (XXXIV)	16	60	24			
5,6- $d_2$ (XL)	11	26	63			

<sup>a</sup> Corrected for natural abundance of C<sup>13</sup>.

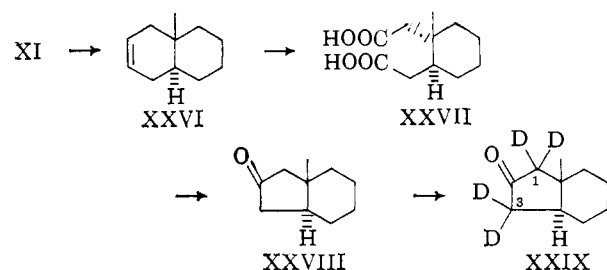
Alternatively, the monodeuteriotosylate XIII was treated with lithium aluminum deuteride to afford the octalin XVII, which when subjected to permanganate-metaperiodate oxidation<sup>14</sup> and pyrolysis of the resulting diacid XVIII<sup>15</sup> furnished *trans*-8-methylhydrindan-2-one-5,5- $d_2$  (XIX).

Deuterium exchange of the octalone XI with deuterium oxide and sodium methoxide in methanol- $d_1$  provided the tetradeuterated derivative XX, which was treated successively with lithium aluminum hydride (XXI), *p*-toluenesulfonyl chloride (XXII), and lithium aluminum hydride to afford the expected tetradeuterated octalin XXIII. This substance was then oxidized to the diacid XXIV and the latter pyrolyzed



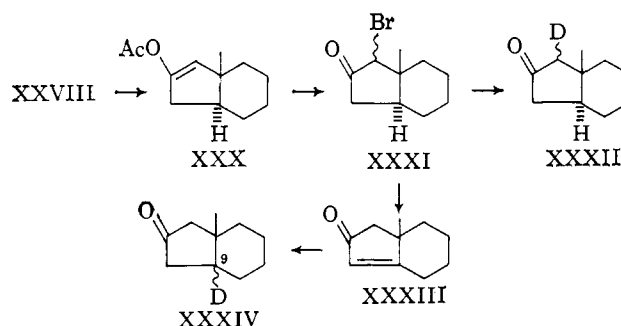
to *trans*-8-methylhydrindan-2-one-4,4,6,6- $d_4$  (XXV).

Preparation of nondeuterated *trans*-8-methylhydrindan-2-one was accomplished by Huang-Minlon reduction<sup>13</sup> of octalone XI to the octalin XXVI, followed by potassium permanganate-sodium metaperiodate oxidation<sup>14</sup> to the diacid XXVII. Pyrolysis of



the latter provided *trans*-8-methylhydrindan-2-one (XXVIII).<sup>15</sup> Deuterium exchange of the four  $\alpha$ -hydrogens to give *trans*-8-methylhydrindan-2-one-1,1,3,3- $d_4$  (XXIX) required refluxing with sodium methoxide and deuterium oxide in methanol- $d_1$  for 18 days, a shorter reaction time affording only partially exchanged material.

The synthesis of *trans*-8-methylhydrindan-2-ones monodeuterated at positions 1 and 9 required the intermediacy of the bromo ketone XXXI. The slow formation of the tetradeuterio ketone XXIX prompted us to prepare the desired bromo ketone XXXI via the enol acetate XXX and subsequent bromination of the latter material with bromine in chloroform, as had



been described previously by Dauben, *et al.*,<sup>18</sup> for the  $\alpha$ -bromination of A-norcholestan-2-one. Vapor phase chromatography of the bromination product indicated a mixture of two compounds. Since vapor phase chromatography of the starting material revealed the presence of only one enol acetate and since there is presumptive evidence that enolization of *trans*-8-methylhydrindan-2-one proceeds toward C-1 (see XXX),<sup>18</sup> we conclude that the bromination mixture consists of C-1 epimers of *trans*-1-bromo-8-methylhydrindan-2-one. This conclusion is supported by the nuclear magnetic resonance spectrum which exhibited only a singlet at  $\delta$  3.88, whereas the 3-bromo isomer would be expected to exhibit a doublet in this region.

Reaction of the bromo ketone XXXI with zinc in freshly prepared deuterioacetic acid<sup>19</sup> at room temperature afforded *trans*-8-methylhydrindan-2-one-1- $d_1$  (XXXII). Alternatively, refluxing the bromo ketone XXXI with lithium chloride in dimethylformamide resulted in the formation of the  $\alpha,\beta$ -unsaturated ketone XXXIII.<sup>18, 20</sup> The structure of this product was confirmed by spectroscopic evidence: infrared spectrum (film), 5.82 (s) and 6.13  $\mu$  (s); nuclear magnetic resonance spectrum, singlet at  $\delta$  5.84; ultraviolet spectrum,  $\lambda_{\max}^{\text{EtOH}}$  230 m $\mu$  ( $\epsilon$  4150); mass spec-

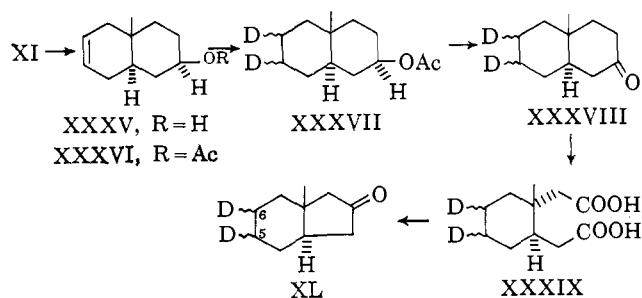
(18) W. G. Dauben, G. A. Boswell, and W. H. Templeton, *J. Am. Chem. Soc.*, **83**, 5006 (1961).

(19) M. J. Dewar and R. C. Fahey, *ibid.*, **85**, 2245 (1963).

(20) For a discussion of this reaction see W. F. Jones, *J. Org. Chem.*, **28**, 1616 (1963).

trum, molecular ion peak at  $m/e = 150$ . Lithium in liquid trideuterioammonia reduction of the hydrindanone XXXIII with ammonium chloride work-up afforded the desired hydrindanone deuterated at C-9 (*i.e.*, XXXIV). Vapor phase chromatography revealed only a single peak, with a retention time identical with that of the nonlabeled analog. This is surprising, since the production of a mixture of *cis*- and *trans*-fused systems, predominating in the former, had been anticipated.<sup>21</sup> It is most likely that the *cis* and *trans* isomers of XXXIV were not resolved chromatographically in our system.

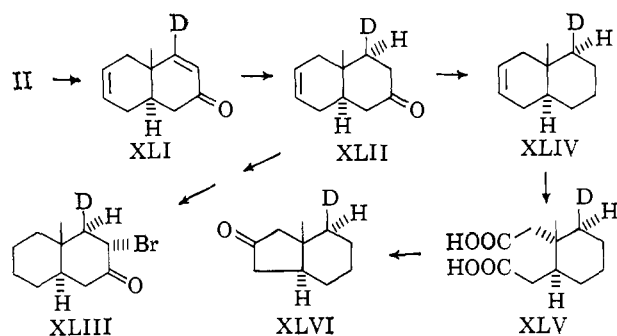
*trans*-8-Methylhydrindan-2-one-5,6- $d_2$  was prepared in the following fashion. Lithium aluminum hydride reduction of the octalone XI gave the octalol XXXV, which was acetylated with acetic anhydride in pyridine to the acetoxy derivative XXXVI and converted to the dideuterated acetoxydecalin XXXVII in moderate yield (major con-



taminant being starting material) by a diimide reaction.<sup>22</sup> (N,N,N-Trideuterio-*p*-toluenesulfonylhydrazide, prepared by recrystallization of *p*-toluenesulfonylhydrazide from deuterium oxide, served as the dideuteriodiimide source in this reaction. The isotopic purity of this trideuterio reagent was shown to be greater than 90% by infrared spectroscopy.)

Saponification of this dideuterio product, XXXVII, followed by Jones oxidation<sup>23</sup> resulted in the formation of the expected dideuteriodecalone XXXVIII. The latter material was converted in poor yield to the diacid XXXIX by nitric acid oxidation.<sup>24</sup> Subsequent pyrolysis<sup>15</sup> resulted in the formation of the desired *trans*-8-methylhydrindan-2-one-5,6- $d_2$  (XL).

The final 7 $\beta$ -monodeuterated analog (XLVI) of *trans*-8-methylhydrindan-2-one was prepared starting from the enol ether II, which was converted to the monodeuteriohexalone XLI by lithium aluminum deuteride reduction followed by refluxing with sulfuric acid. Lithium in liquid ammonia reduction of XLI afforded the monodeuteriooctalone XLII. The stereochemistry at C-4 of the latter material was determined by inspection of the nuclear magnetic resonance spectrum of the bromo ketone XLIII, prepared from XLII by hydrogenation over platinum oxide followed by bromination with bromine in acetic acid.<sup>11</sup> The bromo ketone XLIII exhibited a doublet in its nuclear magnetic resonance spectrum at  $\delta$  4.67 and 4.90 with a coupling constant of 14 c.p.s., suggesting an axial-



axial relationship of the relevant hydrogens.<sup>12</sup> Hence the deuterium atom in the octalone XLII is equatorial (*i.e.*,  $\beta$ ) and therefore lithium in liquid ammonia reduction of the  $\alpha,\beta$ -unsaturated ketone XLI proceeded by axial approach of hydrogen at the  $\beta$ -position.<sup>23</sup> Transformation of XLII to the octalin XLIV, the diacid XLV, and then to *trans*-8-methylhydrindan-2-one-7 $\beta$ - $d_1$  (XLVI) was performed as described in the preparation of *trans*-8-methylhydrindan-2-one-7 $\alpha$ - $d_1$  (VIII).

### Discussion of Mass Spectra

Before discussing the mass spectral fragmentations of  $\beta$ -hydrindanones, the following difficulties in interpretation should be noted.

(i) The hydrindanone molecule does not have a site which is extremely apt to localize a positive charge and thus direct the fragmentation essentially from one center. A multiplicity of fragmentation paths is therefore to be expected, as has been noted with steroid ketones.

(ii) A given peak may, and in many cases does, comprise two species differing in elemental composition. For example, the peak at  $m/e = 95$  is composed of  $\text{C}_7\text{H}_{11}$  and  $\text{C}_6\text{H}_7\text{O}$  in a ratio of 8:2. These features are revealed by high-resolution measurements<sup>26</sup> and the multiple composition of certain peaks is compiled in Table II. However, upon introduction of deuterium these two species will shift in different ways in the spectrum of a deuterated compound which adds to the difficulty of interpretation.

Table II. High-Resolution Determination of Prominent Peaks in Mass Spectrum of *trans*-8-Methylhydrindan-2-one<sup>a</sup>

Peak, $m/e$	Elemental compn.	%
81	$\text{C}_6\text{H}_9$	85
	$\text{C}_5\text{H}_5\text{O}$	15
95	$\text{C}_7\text{H}_{11}$	80
	$\text{C}_6\text{H}_7\text{O}$	20
108	$\text{C}_8\text{H}_{12}$	100
109	$\text{C}_8\text{H}_{12}$	85
	$\text{C}_7\text{H}_9\text{O}$	15
110	$\text{C}_8\text{H}_{14}$	90
	$\text{C}_7\text{H}_{10}\text{O}$	10
124	$\text{C}_9\text{H}_{16}$	30
	$\text{C}_8\text{H}_{12}\text{O}$	70

<sup>a</sup>  $\pm 5\%$ .

(21) Private communication from Professor W. G. Dauben of the University of California, Berkeley, Calif.

(22) R. S. Dewey and E. E. van Tamelen, *J. Am. Chem. Soc.*, **83**, 3729 (1961).

(23) K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. L. Weedon, *J. Chem. Soc.*, 39 (1946).

(24) B. Riniker, J. Kalvoda, D. Arigoni, A. Furst, O. Jeger, A. M. Gold, and R. B. Woodward, *J. Am. Chem. Soc.*, **76**, 312 (1954).

(25) For a pertinent discussion of this reaction see G. Stork and S. D. Darling, *ibid.*, **86**, 1761 (1964).

(26) See J. H. Beynon, "Mass Spectrometry and its Application to Organic Chemistry," Elsevier Publishing Co., Amsterdam, 1960, Chapters I and 2; R. D. Craig and G. A. Ercock in "Advances in Mass Spectrometry," J. D. Waldron, Ed., Pergamon Press Ltd., London, 1959, pp. 66-85.

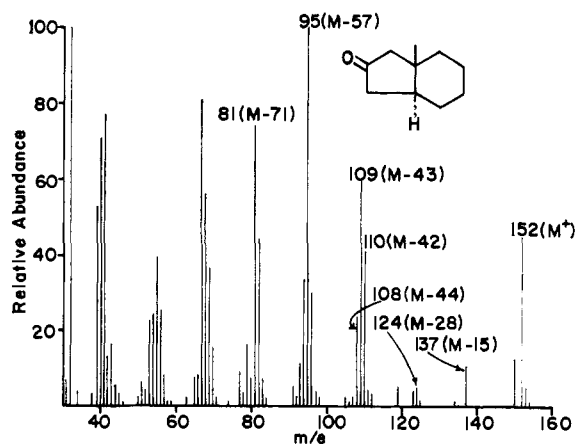


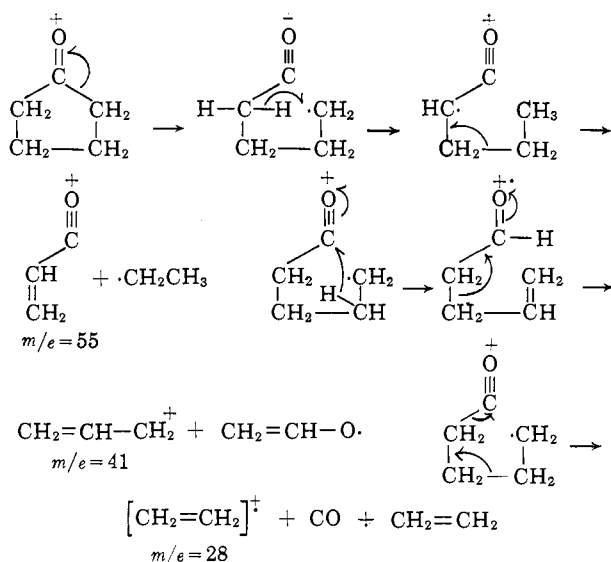
Figure 1. Mass spectrum of *trans*-8-methylhydrindan-2-one.

(iii) A fragment of a given elemental composition can be formed by different mechanisms comprising hydrogen atoms which originate from different loci. Again upon deuterium labeling such a peak will be split. A pertinent example is the  $C_7H_{11}$  portion of the  $m/e = 95$  peak.

(iv) As can be seen from inspection of Figure 1, the mass spectrum of *trans*-8-methylhydrindan-2-one (XXVIII) is characterized by peak groups rather than outstanding single peaks. Shifts of those smaller satellites of an abundant fragment upon deuteration can result in incidental overlaps, thus again complicating a simple following of peak shifts.

(v) Synthetic introduction of deuterium often leads to appreciable amounts of over- or underdeuterated species (see Table I), which complicate the interpretation of fragmentation mechanisms and hydrogen transfer reactions.

The mass spectrum of cyclopentanone has been investigated by Natalis.<sup>27</sup> The base peak at  $m/e = 55$  and the dominant peaks at  $m/e = 41$  and  $m/e = 28$  have been shown with the aid of the 2,2,4,4-*d*<sub>4</sub> analog to originate by the following processes<sup>27, 28</sup>

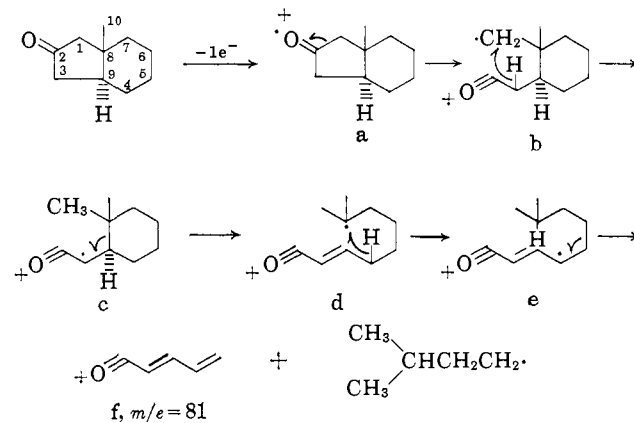


(27) P. Natalis, *Bull. soc. chim. Belges*, **67**, 599 (1958).

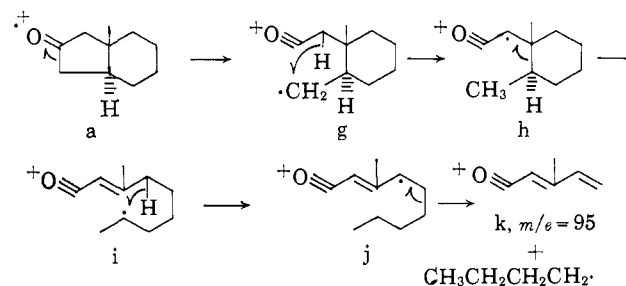
(28) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Interpretation of Mass Spectra of Organic Compounds," Holden-Day Inc., San Francisco, Calif., 1964, Chapter I. See also F. W. McLafferty in "Determination of Organic Structures by Physical Methods," Vol. 2, F. C.

Note that the genesis of these principal fragments can be rationalized by a primary ionization of the carbonyl group,<sup>28</sup> followed by the usual  $\alpha$ -cleavage.<sup>29</sup>

When our work was initiated we anticipated similar fragmentation processes in the case of *trans*-8-methylhydrindan-2-one, that is, primary ionization of the carbonyl group to give molecular ion a, which then would be expected to fragment in two ways. Cleavage of the 1-2 bond results in formation of b, which might undergo a hydrogen migration *via* a five-membered transition state, producing species c. Homolysis of the 8-9 bond would generate d, the driving force being formation of a conjugated system. A second hydrogen transfer, this time from C-4, *via* a six-membered transition state to C-8 can yield an allylic radical e, which then suffers homolysis at the 5-6 bond to form species



f ( $m/e = 81$ ). Alternatively,  $\alpha$ -cleavage at the 2-3 bond of a followed by a similar sequence (a  $\rightarrow$  g  $\rightarrow$  h  $\rightarrow$  i  $\rightarrow$  j  $\rightarrow$  k) would afford k ( $m/e = 95$ ). A com-



pletely analogous series of steps has already been demonstrated in various ethylene ketals.<sup>30</sup> Indeed, the mass spectrum of *trans*-8-methylhydrindan-2-one (XXVIII), reproduced in Figure 1, exhibits a base peak at  $m/e = 95$  and an intense peak at  $m/e = 81$ . However, the mass spectra of the deuterated analogs are clearly inconsistent with this formulation as f and k, as the main fragments, as can be seen from Table III, and from high-resolution data (see Table II) which show that only 20 and 15%, respectively, of these peaks correspond to oxygenated species.

The mass spectra of the deuterated analogs (Table III) reveal that the prominent peaks are formed in a

Nachod, and W. D. Phillips, Ed., Academic Press Inc., New York, N. Y., 1962, p. 174.

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

(30) H. Audier, A. Diara, M. de J. Durazo, M. Fetizon, P. Foy, and W. Vetter, *Bull. soc. chim. France*, 2827 (1963); G.-von Mutzenbecher, Z. Pelah, D. H. Williams, H. Budzikiewicz, and C. Djerassi, *Steroids*, **2**, 475 (1963).

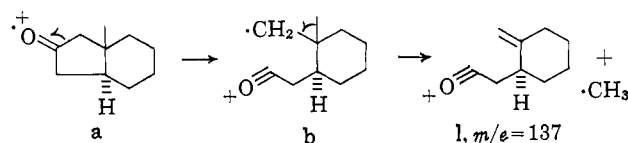
**Table III.** Abundance of Peaks (%) of Total Ionization of a Given Group<sup>a,b</sup>

Compd.												<i>m/e</i> , %									
	81	82	83	84	85	86	94	95	96	97	98	99	100	108	109	110	111	112	113	114	
XXVIII	63	37					20	62	18					19	48	33					
VIII <sup>c</sup>	20	46	34				12	23	46	19				6	15	38	34	7			
XLVI	27	53	20				9	26	49	16					22	46	32				
XVI	16	57	27				6	31	48	15					21	47	32				
XIX	13	18	44	25				17	22	46	15				18	12	40	30			
XXV	7	14	23	30	20	6			9	24	16	39	12			7	11	26	29	27	
XXIX	21	16	30	24	9		20	25	22	27	6					15	43	32	10		
XXXII <sup>c</sup>	39	29	32				25	27	32	16						41	30				
XXXIV <sup>c</sup>	25	48	27				12	38	35	15				18	11	41	30				
XL <sup>c</sup>	12	34	40	14			7	13	34	35	11			6	14	21	37	22			

<sup>a</sup> ±4%. <sup>b</sup> Only values >5% are considered. <sup>c</sup> Corrected for *d*<sub>0</sub> contaminant.

somewhat random manner. These peaks will now be considered in detail. All elemental compositions have been confirmed by high-resolution measurements (see Table II). Only values above 5% of the major component are given.

**Peak M - 15 (*m/e* = 137 in Figure 1).** This peak remains unchanged in all the deuterated analogs. Since the β-hydrindanone analogs contain deuterium in every ring position, the 15 mass units which are lost must involve the angular methyl group.<sup>31</sup> For this process the following mechanism may be written: the usual α-cleavage<sup>29</sup> to give species b, followed by homolysis of the 8-10 bond to give a methyl radical and l (M - 15). This postulated path seems preferable to simple elision of the methyl group from a.



**Peak M - 28 (*m/e* = 124 in Figure 1).** As may be seen from Table II this peak comprises about 2/3 loss of C<sub>2</sub>H<sub>4</sub> and 1/3 loss of CO. Owing to the low intensity of this peak and to the presence of neighboring species (M - 29, etc.) it is virtually impossible to follow shifts in the deuterated analogs.

**Peak M - 42 (*m/e* = 110 in Figure 1).** The M - 42 peak represents 40% of the base peak. It is shifted predominantly to M - 44 in the mass spectrum of the 1,1,3,3-*d*<sub>4</sub> analog XXIX (Table III), suggesting that C-1 or C-3 together with its two hydrogen atoms is lost. The mass spectrum of the 1-*d*<sub>1</sub> compound XXXII exhibits the peak at M - 42, clearly demonstrating that it is C-3 which is expelled in this fragmentation process. An attractive mechanism involves α-cleavage (a → b) followed by heterolysis of the 3-9 bond with formation of the charged species m (M - 42)—formally an ionized cyclopropane—and loss of the neutral fragment as ketene.

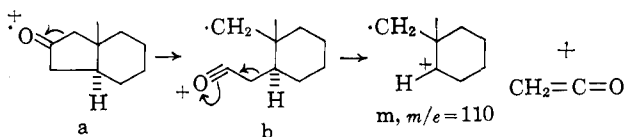
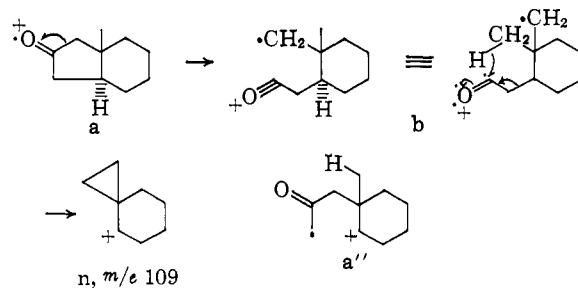


Table III reveals that a substantial portion of the M - 42 peak occurs at M - 43 in compound XXIX.

(31) As shown in ref. 2b, a methyl radical can also be lost from a nuclear methylene position by hydrogen migration.

This suggests that a fragmentation process involving loss of C-3 with one of its hydrogens plus an additional hydrogen atom comprises this competing mode of cleavage. The second hydrogen atom which is lost appears to originate from C-9 (see compound XXXIV), thus requiring a mechanism involving a double-hydrogen transfer, a process not uncommon in mass spectral fragmentation processes.<sup>4,32</sup>

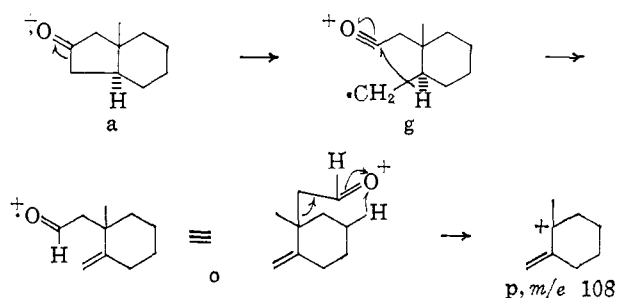
**Peak M - 43 (*m/e* = 109 in Figure 1).** The predominant occurrence of this peak at M - 43 save for compound XXIX (Table III) indicates it to be derived by loss of C<sub>2</sub>H<sub>3</sub>O. This is confirmed by high-resolution data (see Table II). As in the case of the M - 42 peak, compounds XXIX and XXXII implicate mainly C-3 with its two hydrogens as being involved in the eliminated moiety. That the M - 43 peak is not shifted in the other deuterated analogs leaves only the angular methyl group as the source of the third hydrogen atom of the 43 mass units which are lost. With this in mind, we suggest the following possible mechanism: α-cleavage of the 1-2 bond results in the formation of species b which can transfer a hydrogen atom from C-10 with concomitant fission of the 3-9 bond giving rise to fragment n (M - 43). Heterolysis of the 3-9 bond is assumed arbitrarily and no evidence of this possibility as compared to several other equally likely ones (including intervention of a molecular ion such as a'') can be presented.



**Peak M - 44 (*m/e* = 108 in Figure 1).** As can be seen from Table II this fragment is comprised entirely of C<sub>8</sub>H<sub>12</sub>. Table III indicates that, although the *m/e* = 108 species finds its origin by a somewhat random process, the C<sub>2</sub>H<sub>4</sub>O entity which is lost is predominantly derived from C-1 with its pair of hydrogens (see XXIX and XXXII), C-2 with its oxygen atom, and a hydrogen atom from C-9 (see compound XXXIV) and C-6 (see compounds XXV and

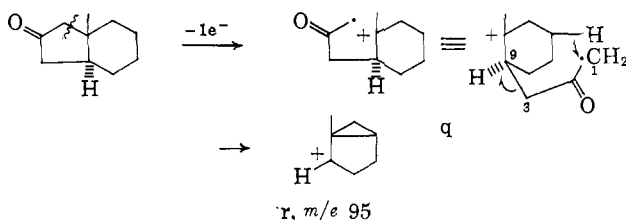
(32) D. H. Williams, J. M. Wilson, H. Budzikiewicz, and C. Djerassi, *J. Am. Chem. Soc.*, **85**, 2091 (1963).

XL). A mechanism in accord with these observations involves  $\alpha$ -cleavage to form g followed by a homolytic hydrogen transfer from C-9 to C-2, producing o. The latter may transfer a hydrogen atom from C-6 as shown below, discharging vinyl alcohol as a neutral moiety and forming fragment p ( $m/e = 108$ ), for which one possible resonance form is shown.

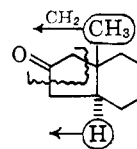


Peak  $M - 57$  ( $m/e = 95$  in Figure 1). The peak at  $m/e = 95$  is the base peak in the spectrum in Figure 1. Analogs deuterated in ring B maintain a major portion of the peak at  $M - 57$ , indicating that the lost species corresponds to  $C_3H_5O$  rather than  $C_4H_9$ . (This has been confirmed by high-resolution measurements, see Table II.) Although the mass spectrum of the 1,1,3,3- $d_4$  derivative shows a group of peaks of comparable intensity at  $m/e = 94$  to 97, the high-resolution spectrum of this analog has served to clarify the origin and mechanism for the formation of the  $M - 57$  fragment. Thus the peaks at  $m/e = 94$  and 96 are comprised of  $C_7H_{10}$  and  $C_7H_{12}$ , respectively, and bear no relationship to the  $M - 57$  peak ( $C_7H_{11}$ ) in *trans*-8-methylhydrindan-2-one. The fragment at  $m/e = 95$  ( $M - 61$ ) is composed of  $C_7H_{11}$ , while the elemental composition of the  $m/e = 97$  peak ( $M - 59$ ) corresponds to  $C_7H_9D_2$ , clearly showing that the  $M - 57$  peak of *trans*-8-methylhydrindan-2-one is generated by two processes which occur with equal frequency. One of these fragmentation patterns involves loss of ring A together with an additional hydrogen atom. It is noted that in the mass spectrum of the 9- $d_1$  analog that a majority of the label is lost. One cannot distinguish with which mechanism the C-9 hydrogen is lost; however, it is less likely that this transfer would occur with the loss of ring A since this would involve transfer of a hydrogen from a carbon atom whose bond is to be broken.

Inspection of the compounds deuterated at C-4, C-5, and C-6 reveals that a substantial loss of the C-6 hydrogen has occurred. A plausible mechanism therefore would involve cleavage of the 1-8 bond with loss of an electron to form the species q, containing a tertiary carbonium ion and a resonance-stabilized radical. Transfer of a hydrogen from C-6 to C-1 with homolysis of the 3-9 bond gives rise to expulsion of an acetyl radical and the charged fragment r ( $m/e = 95$ ).



The other fragmentation leading to an  $M - 57$  peak most likely involves loss of C-1 with its attached hydrogens, the C-2 carbonyl group, and one hydrogen atom, which is predominantly derived from C-9 (see Table III). The data suggest that the remaining 14 mass units are expelled from the angular methyl group. Indicated below is the part of the molecule which is lost, although its mode of cleavage is not apparent.



Peak  $M - 71$  ( $m/e = 81$  in Figure 1). The mass spectrum of the 1,1,3,3- $d_4$  analog indicates that in part two deuterium and four deuterium atoms are lost. Examination of the spectrum of the 1- $d_1$  derivative (XXXII) shows that C-1 with its hydrogens is lost to a considerable extent. However, analysis of the spectra of the remaining deuterated analogs indicates random deuterium loss from ring B.

### General Conclusions

Our results support the earlier conclusion<sup>33</sup> that the carbonyl group does not direct fragmentation of bicyclic systems in a predictable manner. The mass spectra of deuterated analogs of *trans*-8-methylhydrindan-2-one reveal that these compounds undergo somewhat complicated fragmentation patterns (e.g.,  $M - 71$ ) which cannot be correlated mass spectrometrically with related systems such as 16-keto steroids, but which can be of diagnostic value from a mechanistic standpoint.

Going from a cyclopentanone to a  $\beta$ -hydrindanone system leads to profound changes in the mass spectra. Preliminary examination of *trans*-8-methylhydrindan-2-one suggested mechanistic analogy to the fragmentation pattern of cyclopentanone. However, a study of deuterated analogs of the former coupled with high-resolution mass measurements established that this was in fact not the case. These results indicate that caution should be exercised before definite conclusions are drawn about a molecule's mechanistic fate as anticipated from a simpler model compound. The use of deuterated derivatives and high-resolution measurements are valuable methods for determining mass spectrometric fragmentation behavior and when applied simultaneously can be used to elucidate fairly complex fragmentation mechanisms (e.g.,  $M - 57$  peak).

### Experimental<sup>34</sup>

*trans*-2-Keto-10-methyl- $\Delta^6$ -octahydronaphthalene-3,4- $d_2$  (IV). To a prerduced suspension of 0.5 g.

(33) Ref. 28, p. 140.

(34) Melting points were determined on a Kofler hot state and are corrected. All low-resolution mass spectra were determined with a Consolidated Electro-dynamics Corp. No. 21-103C mass spectrometer 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  $\mu$ a. High-resolution mass spectral measurements were performed by Dr. D. A. Lightner, using an MS-9 double-focusing mass spectrometer. Analytical thin layer chromatoplates with a thickness of 0.25 mm. of silica gel G (E. Merck A.-G., Darmstadt) were utilized in a 15% ether-85% benzene solvent, and the spots were detected by spraying with a 2% ceric sulfate solution in 2 N sulfuric acid.

of 2% palladium-on-calcium carbonate catalyst in 50 ml. of cyclohexane was added a solution of 1.45 g. of hexalone III,<sup>7</sup> in 30 ml. of cyclohexane, followed by shaking in the presence of deuterium gas until 290 cc. of deuterium was absorbed (2.3 hr.). The catalyst was filtered and the filter cake was washed well with cyclohexane. The solvent was evaporated under reduced pressure to afford a gray liquid (IV):  $\lambda_{\text{max}}^{\text{film}}$  5.82 (s) and 4.65  $\mu$  (w), indicative of a C-D stretching vibration; mass spectrum ( $m/e$  values) 164 ( $d_0$ , 2%), 165 ( $d_1$ , 20%), 166 ( $d_2$ , 30%), 167 ( $d_3$ , 17%), 168 ( $d_4$ , 8%), 169 ( $d_5$ , 9%), 170 ( $d_6$ , 9%), and 171 ( $d_7$ , 5%).

*trans-2-Keto-10-methyl- $\Delta^6$ -octahydronaphthalene-4 $\alpha$ - $d_1$*  (V). The crude dideuterated octalone IV was dissolved in 10 ml. of methanol and 7 ml. of 5% aqueous sodium hydroxide and heated under reflux for 30 min. The solution was cooled and the methanol was evaporated under reduced pressure. The remaining yellow liquid was extracted with diethyl ether and the ether was removed under diminished pressure. This procedure was repeated two additional times, the final ether extracts being washed with dilute hydrochloric acid and water and dried over anhydrous magnesium sulfate. The solvent was removed under reduced pressure to leave a yellow liquid which was chromatographed on 60 g. of neutral alumina (activity II) using benzene as eluent. This afforded 1.06 g. of V:  $\lambda_{\text{max}}^{\text{film}}$  4.70 (w) and 5.83  $\mu$  (s); mass spectrum ( $m/e$  values) 164 ( $d_0$ , 8%), 165 ( $d_1$ , 36%), 166 ( $d_2$ , 23%), 167 ( $d_3$ , 8%), 168 ( $d_4$ , 7%), 169 ( $d_5$ , 11%), 170 ( $d_6$ , 6%), and 171 ( $d_7$ , 1%).

*trans-9-Methyl- $\Delta^2$ -octahydronaphthalene-8 $\alpha$ - $d_1$*  (VI). A solution of 0.90 g. of monodeuteriooctalone V in 25 ml. of diethylene glycol and 5 ml. of 95% hydrazine was slowly heated to 140° under nitrogen and kept at this temperature for 1 hr. The solution was then cooled to 130° and 1.9 g. of potassium hydroxide pellets were added, one pellet at a time. The solution was heated and the distillate was withdrawn until a temperature of 195° was attained, whereupon reflux was maintained for 4.5 hr. The solution was cooled, poured into water, and extracted with diethyl ether. The combined extracts were washed with dilute sulfuric acid and water and dried over anhydrous magnesium sulfate. Solvent was removed under reduced pressure to leave a pale yellow oil which was chromatographed on 30 g. of neutral alumina (activity II) using petroleum ether (b.p. 60–68°) as eluent. This provided 570 mg. of VI:  $\lambda_{\text{max}}^{\text{film}}$  4.66  $\mu$  (w) (absence of carbonyl absorption); mass spectrum ( $m/e$  values) 150 ( $d_0$ , 8%), 151 ( $d_1$ , 30%), 152 ( $d_2$ , 20%), 153 ( $d_3$ , 7%), 154 ( $d_4$ , 8%), 155 ( $d_5$ , 16%), 156 ( $d_6$ , 9%), and 157 ( $d_7$ , 1%).

*trans-1-Methylcyclohexane-1,2-diacetic-6 $\alpha$ - $d_1$*  Acid (VII). Oxidation of the olefin VI to the dicarboxylic acid was carried out by a modification of the Lemieux oxidation.<sup>14</sup> To a solution of 220 mg. of monodeuteriooctalin VI in 80 ml. of *t*-butyl alcohol was added a solution of 2 g. of sodium carbonate in 30 ml. of water, followed by 15 ml. of 8% sodium metaperiodate and 2 ml. of 2% potassium permanganate. An additional 60 ml. of 8% sodium metaperiodate solution was added dropwise. The resulting violet solution was stirred at room temperature for 4.5 hr. after addition was completed, additional potassium permanganate

being added periodically to maintain the characteristic violet color. Excess oxidizing agent was destroyed by adding solid sodium bisulfite until the solution had attained a yellow color. The two-phase mixture was evaporated under reduced pressure to approximately one-half its initial volume, whereupon a white solid separated. The mixture was acidified with 5 ml. of a chilled solution of 50% sulfuric acid and extracted with diethyl ether. The combined ether extracts were washed with dilute sodium bisulfite and water and dried over anhydrous magnesium sulfate. The solvent was evaporated under reduced pressure to leave a pale yellow solid (VII), which was recrystallized from acetone-chloroform to afford 142 mg. of colorless solid, m.p. 190–193.5°.

*trans-8-Methylhydrindan-2-one-7 $\alpha$ - $d_1$*  (VIII).<sup>15</sup> A mixture of 140 mg. of the diacid VII and 11 mg. of anhydrous barium hydroxide was slowly heated in a microdistillation apparatus to 300° and maintained at 310–330° for 30 min., at which time a pale yellow liquid accumulated in the microdistillation tube. The reaction mixture was allowed to cool to room temperature and the entire mixture was extracted with diethyl ether. The ethereal solution was washed with 5% hydrochloric acid, 5% sodium bicarbonate, and water and dried over anhydrous magnesium sulfate. The solvent was evaporated under diminished pressure to leave 73 mg. of a yellow oil which was chromatographed on 7 g. of neutral alumina (activity II), using benzene as eluent, to provide 60 mg. of a faintly yellow oil (VIII):  $\lambda_{\text{max}}^{\text{film}}$  5.72 (s) and 4.77  $\mu$  (w); mass spectrum ( $m/e$  values) 152 ( $d_0$ , 16%), 153 ( $d_1$ , 61%), 154 ( $d_2$ , 20%), and 155 ( $d_3$ , 3%). A vapor phase chromatogram on a 5% diethylene glycol succinate on 60/80 firebrick column at 180° revealed only a single peak. The 2,4-dinitrophenylhydrazone was recrystallized from ethanol, m.p. 155–157°.

*trans-3-Bromo-10-methyldecal-2-one-4 $\alpha$ - $d_1$*  (X).<sup>11</sup> To a prerduced suspension of 10 mg. of platinum oxide in 5 ml. of methanol was added a solution of 30 mg. of deuteriooctalone V in methanol. The mixture was stirred in the presence of hydrogen for 3 hr., the catalyst was filtered, and the filter cake was washed with methanol. The filtrate was passed over a column of neutral alumina (activity II) wet-packed with benzene, and then the solvent was removed under vacuum, leaving a milky oil which was distilled at 65–67° at 0.1 mm. to afford 12 mg. of product (IX).

The product IX was dissolved in 1 ml. of glacial acetic acid and a solution of 12 mg. of bromine in 1 ml. of glacial acetic acid was added dropwise with cooling in an ice-water bath. The resulting solution was stirred at room temperature for an additional hour, after which time water was added dropwise and the resulting cloudy solution was allowed to crystallize overnight. The mixture was filtered to provide 3.8 mg. of product, m.p. 136–138°, n.m.r. doublet centered at  $\delta$  4.69 and 4.80,  $J = 5.8$  c.p.s.

*trans-2-Hydroxy-10-methyl- $\Delta^6$ -octahydronaphthalene-2 $\alpha$ - $d_1$*  (XII). To a stirred suspension of 1.3 g. of lithium aluminum deuteride in 65 ml. of anhydrous diethyl ether was added dropwise a solution of 4.6 g. of octalone XI<sup>16</sup> in 100 ml. of anhydrous diethyl ether. The resulting mixture was heated under reflux overnight in an atmosphere of nitrogen. The mixture was cooled and



ethyl acetate was added to destroy excess lithium aluminum hydride, followed by addition of an aqueous, saturated solution of sodium sulfate. The mixture was heated under reflux until colorless. After cooling, the mixture was filtered and the filter cake was washed with diethyl ether. The combined filtrate and washings were concentrated under reduced pressure to afford a colorless oil which was distilled at 100–101° (1.5 mm.) to provide 3.04 g. of XII:  $\lambda_{\text{max}}^{\text{film}}$  4.71 (w), 2.98 (s), and 9.43  $\mu$  (s); mass spectrum ( $m/e$  values) 167 ( $d_1$ , >95%);  $[\alpha]^{25}_{\text{D}} + 67.3^\circ$  ( $c$  1.05).

*trans-2-p-Toluenesulfonyl-10-methyl- $\Delta^6$ -octahydronaphthalene-2 $\alpha$ - $d_1$*  (XIII). To a stirred solution of 3.04 g. of the octalol XII in 25 ml. of pyridine was added a solution of 2.8 g. of *p*-toluenesulfonyl chloride, while cooling in an ice-water bath. The resulting solution was stirred for 1 hr. under nitrogen and left in the coldroom overnight. The solution was quenched by pouring into an ice-water mixture, whereupon a colorless solid crystallized. The crystals were filtered to afford 3.67 g. of the tosylate XIII, which was recrystallized from aqueous methanol: m.p. 56–57°;  $\lambda_{\text{max}}^{\text{CHCl}_3}$  4.20 (w), 7.40 (w), and 8.50  $\mu$  (s).

*Anal.* Calcd. for  $\text{C}_{18}\text{H}_{23}\text{DO}_2\text{S}$ : S, 9.97. Found: S, 9.85.

*trans-9-Methyl- $\Delta^2$ -octahydronaphthalene-6 $\beta$ - $d_1$*  (XIV). To a stirred suspension of 1.0 g. of lithium aluminum hydride in anhydrous diethyl ether was added dropwise a solution of 1.84 g. of tosylate XIII in anhydrous diethyl ether. The mixture was stirred and heated under reflux in a nitrogen atmosphere for 2 hr. To the cooled solution was added ethyl acetate to decompose excess lithium aluminum hydride and then an aqueous, saturated solution of sodium sulfate was added. The mixture was filtered and the filter cake was washed with diethyl ether. The solvent was removed under reduced pressure to afford a yellow oil which was chromatographed over neutral alumina (activity II), wet-packed with *n*-pentane, using *n*-pentane as eluent to afford 375 mg. of product (XIV):  $\lambda_{\text{max}}^{\text{film}}$  4.61  $\mu$  (w); mass spectrum ( $m/e$  values) 151 ( $d_1$ , >95%). Further elution with ethyl acetate afforded 420 mg. of alcohol XII.

*trans-1-Methylcyclohexane-1,2-diacetic-4 $\beta$ - $d_1$  acid* (XV) was prepared from 375 mg. of monodeuteriooctalin XIV, as described above for the preparation of *trans-1-methylcyclohexane-1,2-diacetic-6 $\alpha$ - $d_1$  acid* (VII), to afford 290 mg. of XV, m.p. 191–194°.

*trans-8-Methylhydrindan-2-one-5 $\beta$ - $d_1$*  (XVI) was prepared from the monodeuterio diacid XV (280 mg.), as described above for the formation of *trans-8-methylhydrindan-2-one-7 $\alpha$ - $d_1$*  (VIII). The reaction product was purified and isolated by preparative plate chromatography: mass spectrum ( $m/e$  values) 152 ( $d_0$ , 4%), 153 ( $d_1$ , 94%), and 154 ( $d_2$ , 2%).

*trans-9-Methyl- $\Delta^2$ -octahydronaphthalene-6,6- $d_2$*  (XVII) was prepared by lithium aluminum deuteride reduction of *trans-2-p-toluenesulfonyl-10-methyl- $\Delta^6$ -octahydronaphthalene-2 $\alpha$ - $d_1$*  (XIII, 1.37 g.), as described for the reduction of XIII with lithium aluminum hydride, to afford 120 mg. of product XVII:  $\lambda_{\text{max}}^{\text{film}}$  4.50 (w) and 4.71  $\mu$  (w). Although the molecular ion peak of its spectrum was too weak for calculation of isotopic distribution, the base peak at  $m/e = 98$  indicates the product to be >80%  $d_2$  species.<sup>35</sup>

*trans-1-Methylcyclohexane-1,2-diacetic-4,4- $d_2$  acid* (XVIII) was prepared from 120 mg. of dideuteriooctalin XVII, as described in the preparation of *trans-1-methylcyclohexane-1,2-diacetic-6 $\alpha$ - $d_1$  acid* (VII), to afford 55 mg. of XVIII, m.p. 189–190°.

*trans-8-Methylhydrindan-2-one-5,5- $d_2$*  (XIX) was prepared by pyrolysis of 45 mg. of the dideuterio diacid XVIII, as described in the preparation of *trans-8-methylhydrindan-2-one-7 $\alpha$ - $d_1$* , to afford 3.7 mg. of product (XIX): mass spectrum ( $m/e$  values) 152 ( $d_0$ , 5%), 153 ( $d_1$ , 5%), 154 ( $d_2$ , 83%), and 155 ( $d_3$ , 7%).

*trans-2-Keto-10-methyl- $\Delta^6$ -octahydronaphthalene-1,1,3,3- $d_4$*  (XX). A solution of 2.07 g. of the octalone XI, 1.10 g. of sodium methoxide, 10 ml. of deuterium oxide, and 25 ml. of deuteriomethanol was heated under reflux overnight in an atmosphere of nitrogen. The solution was cooled and concentrated under reduced pressure. The remaining solution was extracted with diethyl ether and dried over anhydrous magnesium sulfate. The solvent was evaporated under reduced pressure leaving a pale yellow oil, which was distilled at 57–68° at 0.05 mm. in a microdistillation apparatus to afford 1.99 g. of material exhibiting only a single spot on thin layer chromatography:  $\lambda_{\text{max}}^{\text{film}}$  4.52 (w), 4.73 (w), and 5.82  $\mu$  (s); mass spectrum ( $m/e$  values) 167 ( $d_3$ , 17%), 168 ( $d_4$ , 77%), and 169 ( $d_5$ , 6%).

*trans-2-Hydroxy-10-methyl- $\Delta^6$ -octahydronaphthalene-1,1,3,3- $d_4$*  (XXI) was prepared by lithium aluminum hydride reduction of 1.97 g. of tetradeuteriooctalone XX, as described for the lithium aluminum deuteride reduction of *trans-2-keto-10-methyl- $\Delta^6$ -octahydronaphthalene* (XI), to afford a cloudy oil which when distilled in a microdistillation apparatus at 73–80° (0.25 mm.) afforded 1.69 g. of a colorless oil. The product (XXI) exhibited a single spot on thin layer chromatography:  $\lambda_{\text{max}}^{\text{film}}$  3.00 (s), 4.51 (w), 4.70 (w), and 9.43  $\mu$  (s); mass spectrum ( $m/e$  values) 169 ( $d_3$ , 17%), 170 ( $d_4$ , 76%), and 171 ( $d_5$ , 7%).

*trans-2-p-Toluenesulfonyl-10-methyl- $\Delta^6$ -octahydronaphthalene-1,1,3,3- $d_4$*  (XXII) was prepared from the tetradeuteriooctalone XXI (1.68 g.), as described in the preparation of *trans-2-p-toluenesulfonyl-10-methyl- $\Delta^6$ -octahydronaphthalene-2 $\alpha$ - $d_1$*  (XIII), to furnish, after recrystallization from petroleum ether, 1.79 g. of XXII, showing a single spot on thin layer chromatographic analysis: m.p. 59–67°;  $\lambda_{\text{max}}^{\text{CHCl}_3}$  4.51 (w), 4.71 (w), 7.37 (s), and 8.50  $\mu$  (s).

*trans-9-Methyl- $\Delta^2$ -octahydronaphthalene-5,5,7,7- $d_4$*  (XXIII) was prepared by lithium aluminum hydride reduction of 1.77 g. of tosylate XXII, as described for the similar reduction of *trans-2-p-toluenesulfonyl-10-methyl- $\Delta^6$ -octahydronaphthalene-2 $\alpha$ - $d_1$*  (XIII), to afford 750 mg. of product (XXIII):  $\lambda_{\text{max}}^{\text{film}}$  4.53 (w) and 4.73  $\mu$  (w); mass spectrum ( $m/e$  values) 153 ( $d_3$ , 17%), 154 ( $d_4$ , 70%), and 155 ( $d_5$ , 13%).

*trans-1-Methylcyclohexane-1,2-diacetic-3,3,5,5- $d_4$  acid* (XXIV) was synthesized from 750 mg. of tetradeuteriooctalin XXIII, as described in the preparation of *trans-1-methylcyclohexane-1,2-diacetic-6 $\alpha$ - $d_1$  acid* (VII), to afford 670 mg. of crystalline material (XXIV) exhibiting a melting point of 187–193°.

(35) The reader is referred to the preceding synthetic discussion for the relevance of this M — 54 peak.

*trans*-8-Methylhydrindan-2-one-4,4,6,6-*d*<sub>4</sub> (XXV).<sup>15</sup> A mixture of 550 mg. of the diacid XXIV and 40 mg. of anhydrous barium hydroxide was slowly heated in a microdistillation tube to 300° and maintained at 310–330° for an additional 30 min., whereupon a pale yellow oil accumulated. The mixture was cooled and extracted with diethyl ether. The combined ether extracts were washed with 5% sodium bicarbonate, dilute hydrochloric acid, and water. After drying over anhydrous magnesium sulfate and evaporating the solvent under diminished pressure, the remaining yellow oil was distilled at 0.05 mm. at 55–65° to afford 268 mg. of a colorless oil (XXV). A vapor phase chromatogram on a 5% diethylene glycol succinate on 60/80 firebrick column exhibited a single peak at 140°:  $[\alpha]^{25D} + 270.96^{\circ 36}$  (*c* 0.62, CHCl<sub>3</sub>);  $\lambda_{\max}^{\text{film}}$  4.58 (w), 4.67 (w), and 5.77  $\mu$  (s); mass spectrum (*m/e* values) 155 (*d*<sub>3</sub>, 15%), 156 (*d*<sub>4</sub>, 83%), and 157 (*d*<sub>5</sub>, 2%).

The 2,4-dinitrophenylhydrazone was recrystallized from ethanol: m.p. 154–155°;  $\lambda_{\max}^{\text{CHCl}_3}$  365 m $\mu$  ( $\epsilon$  25,600).

*trans*-9-Methyl- $\Delta^2$ -octahydronaphthalene (XXVI) was prepared from 1.3 g. of the octalone XI, as described in the preparation of *trans*-9-methyl- $\Delta^2$ -octahydronaphthalene-8 $\alpha$ -*d*<sub>1</sub> (VI), to yield a cloudy oil which was distilled at 53–60° (0.10 mm.), to afford 815 mg. of colorless oil (XXVI). The infrared spectrum of the product did not reveal the presence of a carbonyl group.

*trans*-1-Methylcyclohexane-1,2-diacetic acid (XXVII) was synthesized from the octalin XXVI, as described in the preparation of *trans*-1-methylcyclohexane-1,2-diacetic-6 $\alpha$ -*d*<sub>1</sub> acid (VII), to afford 725 mg. of a colorless, crystalline compound (XXVII), m.p. 191–193°.

*trans*-8-Methylhydrindan-2-one (XXVIII) was prepared from 6.02 g. of the diacid XXVII, as described in the preparation of *trans*-8-methylhydrindan-2-one-7 $\alpha$ -*d*<sub>1</sub> (VIII), to afford 3.46 g. of XXVIII:  $\lambda_{\max}^{\text{film}}$  5.76  $\mu$ ; the mass spectrum exhibited a molecular ion peak at *m/e* = 152;  $[\alpha]^{25D} + 283.76$  (*c* 0.59, CHCl<sub>3</sub>).<sup>36</sup> A vapor phase chromatogram on a 5% diethylene glycol succinate on 60/80 firebrick column at 134° exhibited only a single peak.

The 2,4-dinitrophenylhydrazone was recrystallized from ethanol: m.p. 152–155°;  $\lambda_{\max}^{\text{CHCl}_3}$  364 m $\mu$  ( $\epsilon$  22,200).

*trans*-8-Methylhydrindan-2-one-1,1,3,3-*d*<sub>4</sub> (XXIX). A solution of 300 mg. of *trans*-8-methylhydrindan-2-one (XXVIII), 50 mg. of sodium methoxide, and 2 ml. of deuterium oxide in 4 ml. of methanol-*d*<sub>1</sub> was heated under reflux in a nitrogen atmosphere for 4 days. After cooling, methanol-*d*<sub>1</sub> was evaporated under reduced pressure, anhydrous diethyl ether was added, and the aqueous phase was removed with a pipet. The ether was evaporated under diminished pressure to afford a cloudy oil which was treated with sodium methoxide, deuterium oxide, and methanol-*d*<sub>1</sub> as described above, this process being performed a total of four times (18 days of reaction). The final ethereal solution was dried over anhydrous magnesium sulfate and the solvent was removed under vacuum to afford a cloudy oil. Microdistillation at 50–57° (0.15 mm.) provided 54 mg. of XXIX, a considerable amount of

solid residue remaining in the distillation flask: mass spectrum (*m/e* values) 155 (*d*<sub>3</sub>, 8%), and 156 (*d*<sub>4</sub>, 92%).

*trans*-2-Acetoxy-8-methyl- $\Delta^1$ -hydrindene (XXX). A solution of 1.4 g. of *p*-toluenesulfonic acid and 3.45 g. of *trans*-8-methylhydrindan-2-one (XXVIII) in 140 ml. of freshly distilled isopropenyl acetate was heated under reflux for 5 days, more isopropenyl acetate being added and distillate being withdrawn periodically.<sup>18</sup> After the solution was cooled and concentrated, the remaining brown oil was dissolved in diethyl ether and the ethereal solution washed with 5% sodium bicarbonate, water, and a saturated salt solution. The solvent was evaporated under diminished pressure to leave a brown oil, which was taken up in petroleum ether and passed through a column of 80 g. of neutral alumina (activity II). The eluate was evaporated under reduced pressure, leaving a yellow oil which was distilled at 75–80° (0.20 mm.) in a microdistillation apparatus to provide 2.72 g. of product (XXX):  $\lambda_{\max}^{\text{film}}$  5.68 (s), 6.08 (w), and 8.27  $\mu$  (s). Vapor phase chromatography on a 5% diethylene glycol succinate on 60/80 firebrick column at 125° indicated the product consists of 70% of the enol acetate XXX and 30% starting material.

*trans*-1-Bromo-8-methylhydrindan-2-one (XXXI). To a solution of 2.72 g. of the enol acetate XXX in 250 ml. of carbon tetrachloride was added dropwise, with stirring, a solution of 2.4 g. of bromine in 110 ml. of chloroform,<sup>37</sup> while cooling in an ice bath. After addition was completed, the solution was concentrated under reduced pressure to leave a yellow oil, which was dissolved in diethyl ether. The ethereal solution was washed with aqueous sodium thiosulfate, water, 5% sodium bicarbonate, and water. After drying over anhydrous magnesium sulfate and evaporating the solvent under reduced pressure, the remaining yellow oil was chromatographed on 50 g. of neutral alumina (activity II) using petroleum ether as eluent, and distilled at 65–75° (0.10 mm.), to afford 1.13 g. of a colorless oil (XXXI):  $\lambda_{\max}^{\text{film}}$  5.72  $\mu$  (s). The mass spectrum confirmed the molecular weight of the product through the molecular ion peak at *m/e* = 230 and 232 (due to natural abundance of Br<sup>79</sup> and Br<sup>81</sup>).

*Anal.* Calcd. for C<sub>10</sub>H<sub>15</sub>BrO: C, 51.95; H, 6.49; Br, 34.63. Found: C, 52.48; H, 6.60; Br, 34.83.

Vapor phase chromatography of the reaction product indicated a mixture of two compounds which we assumed to be epimeric at C-1 (see preceding discussion).

*trans*-8-Methylhydrindan-2-one-1-*d*<sub>1</sub> (XXXII). A mixture of 20 mg. of  $\alpha$ -bromo ketone XXXI, 3 ml. of anhydrous diethyl ether, 1.5 ml. of freshly prepared deuterioacetic acid,<sup>19</sup> and 90 mg. of zinc dust was stirred overnight at room temperature. The mixture was filtered and the filter cake was washed well with diethyl ether. The combined filtrate and washings were washed with 5% sodium bicarbonate and water. After drying over anhydrous magnesium sulfate and concentrating under reduced pressure, the remaining yellow oil was distilled at 0.05 mm. below 60° to provide 6 mg. of colorless oil (XXXII): mass spectrum (*m/e* values) 152 (*d*<sub>0</sub>, 23%), 153 (*d*<sub>1</sub>, 57%), 154 (*d*<sub>2</sub>, 14%), and 155 (*d*<sub>3</sub>, 6%).

(36)  $[\alpha]^{25D} + 276^{\circ}$  (*c* 0.10, methanol) reported for the undeuterated optical antipode; ref. 15.

(37) J. Fajkos and J. Joska, *Collection Czech. Chem. Commun.*, 26, 1118 (1961).

*8-Methyl- $\Delta^3$ -hydrinden-2-one (XXXIII).* A solution of 1.10 g. of  $\alpha$ -bromo ketone XXXI, 820 mg. of anhydrous lithium chloride, and 33 ml. of freshly distilled N,N-dimethylformamide was heated under reflux at 150° for 24 hr. under a nitrogen atmosphere.<sup>18</sup> The cooled solution was poured into water and extracted with diethyl ether. The combined ether extracts were washed with 5% sodium bicarbonate and water and dried over anhydrous magnesium sulfate. The solvent was evaporated under diminished pressure and the remaining brown oil was distilled at 0.10 mm. The distillate was chromatographed on 30 g. of neutral alumina (activity II), using 1:1 petroleum ether-benzene as eluent, to afford a yellow oil, which when distilled at 50–53° (0.10 mm.) provided 236 mg. of XXXIII:  $\lambda_{\text{max}}^{\text{film}}$  5.82 (s) and 6.13  $\mu$  (s); n.m.r.  $\delta$  5.84 (singlet), 2.59 (multiplet), 2.27 (singlet), and 1.26 (singlet);  $\lambda_{\text{max}}^{\text{EtOH}}$  230 m $\mu$  ( $\epsilon$  4150). A vapor phase chromatogram on a 5% diethylene glycol succinate on 60/80 firebrick column indicated the purity of the product to be greater than 98%. The mass spectrum exhibited a molecular ion peak at  $m/e = 150$ .

*Anal.* Calcd. for C<sub>10</sub>H<sub>14</sub>O: C, 80.00; H, 9.33. Found: C, 79.67; H, 9.47.

*trans-8-Methylhydrindan-2-one-9-d<sub>1</sub> (XXXIV).* To a solution of lithium in trideuterioammonia (maintained in a Dry Ice-acetone bath and equipped with a Dry Ice-acetone condenser), generated from 40 g. of magnesium nitride and 45 ml. of deuterium oxide, was added a solution of 65 mg. of the enone XXXIII in 2 ml. of anhydrous diethyl ether. The blue solution was stirred for an additional 30 min., after which time trideuterioammonia was permitted to evaporate. A dilute solution of aqueous ammonium chloride was added until the blue color of the solution was discharged. The mixture was added to diethyl ether, separated, and the ethereal solution was washed with dilute hydrochloric acid, 5% sodium bicarbonate, and water. After drying over anhydrous magnesium sulfate, the solvent was removed under reduced pressure to afford a yellow oil, which was distilled at 50–60° (0.05 mm.) to provide 47 mg. of colorless oil (XXXIV):  $\lambda_{\text{max}}^{\text{film}}$  5.71 (s) and 4.68  $\mu$  (w); mass spectrum ( $m/e$  values) 152 ( $d_0$ , 16%), 153 ( $d_1$ , 60%), and 154 ( $d_2$ , 24%). Vapor phase chromatography on a 5% diethylene glycol succinate on 60/80 firebrick column exhibited a single peak identical in retention time with that of *trans-8-methylhydrindan-2-one* (XXVIII).

*trans-2-Hydroxy-10-methyl- $\Delta^6$ -octahydronaphthalene (XXXV)* was prepared by lithium aluminum hydride reduction of the octalone XI (2.03 g.), as described in the preparation of *trans-2-hydroxy-10-methyl- $\Delta^6$ -octahydronaphthalene-2 $\alpha$ -d<sub>1</sub> (XII)*, to afford 2.00 g. of XXXV, b.p. 60–65° (0.05 mm.):  $\lambda_{\text{max}}^{\text{film}}$  3.00  $\mu$  (s). The product was shown to be homogeneous by thin layer chromatographic analysis.

*trans-2-Acetoxy-10-methyl- $\Delta^6$ -octahydronaphthalene (XXXVI).* To a solution of 2.00 g. of the octalone XXXV in 10 ml. of pyridine was added 10 ml. of acetic anhydride. The solution was stirred for 15 min. and allowed to stand overnight at room temperature. The solution was poured into water and extracted with diethyl ether. The combined ether extracts were washed with 5% hydrochloric acid, 5% sodium bicarbonate, and water. After drying over anhydrous

magnesium sulfate and evaporating the solvent under diminished pressure, the remaining oil was distilled from a microdistillation apparatus at 54–68° (0.20 mm.) to afford 2.39 g. of material (XXXVI), exhibiting homogeneity on thin layer chromatographic analysis:  $\lambda_{\text{max}}^{\text{film}}$  5.73 (s) and 8.03  $\mu$  (s).

*trans-10-Methyldecal-2-one-6,7-d<sub>2</sub> (XXXVIII).* A solution of 2.39 g. of the acetate XXXVII and 17.0 g. of N,N,N-trideuterio-*p*-toluenesulfonylhydrazide (prepared by recrystallizing *p*-toluenesulfonylhydrazide from deuterium oxide) in 85 ml. of diethylene glycol dimethyl ether (freshly distilled from lithium aluminum hydride) was heated under reflux in a nitrogen atmosphere for 1.5 hr. To the cooled solution was added a solution of 8 g. of sodium hydroxide in 20 ml. of deuterium oxide and the resulting solution was kept at 85–95° for 1 hr. while in a nitrogen atmosphere. The cooled solution was extracted with ether and washed thoroughly with water. The solvent was evaporated under reduced pressure, leaving a yellow liquid, which was completely saponified by heating under reflux in 20 ml. of 5% potassium hydroxide in methanol for 1 hr. The solution was poured into water and extracted with ether. The combined ether extracts were washed with 5% sodium bicarbonate and water. The ethereal solution was dried over anhydrous magnesium sulfate and the solvent removed under diminished pressure to afford a pale yellow oil.

Jones oxidation<sup>23</sup> of the saponification product afforded a yellow oil, which was distilled at 55–59° (0.15 mm.) to provide 1.35 g. of product. The distillate was chromatographed on 70 g. of neutral alumina (activity II) using 2:1 pentane-benzene as eluent to afford 735 mg. of XXXVIII:  $\lambda_{\text{max}}^{\text{film}}$  5.82 (s) and 4.62  $\mu$  (w); mass spectrum ( $m/e$  values) 164 (31%), 165 (1%), 166 (8%), 167 (16%), and 168 ( $d_2$ , 44%).

*trans-1-Methylcyclohexane-1,2-diacetic-4,5-d<sub>2</sub> acid (XXXIX)* was prepared by nitric acid oxidation<sup>24</sup> of the dideuteriodecalone XXXVIII. To 4 ml. of boiling concentrated nitric acid was added dropwise 735 mg. of the dideuteriodecalone XXXVIII, whereupon a violent reaction ensued with evolution of a brown gas. The solution was heated under reflux for 1 hr. after addition was complete, during which time a white solid formed. The mixture was cooled, allowed to stand overnight, and filtered, and the filter cake was washed with cold water. The solid was recrystallized from acetone-chloroform to afford 163 mg. of material (XXXIX), m.p. 190–191°.

*trans-8-Methylhydrindan-2-one-5,6-d<sub>2</sub> (XL)* was prepared as described in the preparation of *trans-8-methylhydrindan-2-one-7 $\alpha$ -d<sub>1</sub> (VIII)*, to afford 96 mg. of XL:  $\lambda_{\text{max}}^{\text{film}}$  5.72 (s) and 4.61  $\mu$  (w); mass spectrum ( $m/e$  values) 152 ( $d_0$ , 11%), 153 ( $d_1$ , 26%), and 154 ( $d_2$ , 63%).

The 2,4-dinitrophenylhydrazone was recrystallized from ethanol: m.p. 151–154°;  $\lambda_{\text{max}}^{\text{CHCl}_3}$  365 m $\mu$  ( $\epsilon$  21,400).

*trans-2-Keto-10-methyl- $\Delta^{3,6}$ -hexahydronaphthalene-4-d<sub>1</sub> (XLI)* was prepared from the enol ether II (9.95 g.) by reduction with lithium aluminum deuteride and subsequent hydrolysis with aqueous sulfuric acid, as described<sup>7</sup> in the synthesis of the nondeuterated compound III, to furnish 7.67 g. of a yellow oil. Distilla-

tion at 57–60° (0.05 mm.) afforded 5.07 g. of XLI: infrared spectrum 5.97  $\mu$  (s); mass spectrum (*m/e* values) 162 (*d*<sub>0</sub>, 5.5%), 163 (*d*<sub>1</sub>, 92.5%), and 164 (*d*<sub>2</sub>, 2%).

*trans-2-Keto-10-methyl- $\Delta^6$ -octahydronaphthalene-4 $\beta$ -d<sub>1</sub>* (XLII). To a solution of 2.0 g. of lithium in approximately 200 ml. of liquid ammonia was added dropwise a solution of 4.00 g. of the hexalone XLI in 100 ml. of anhydrous diethyl ether.<sup>38</sup> A Dry Ice-acetone condenser was used to maintain the liquid ammonia, but no external cooling was applied to the reaction flask. After addition was completed, the reaction was stirred for 2 additional hr., more ammonia being liquified during this time. Anhydrous diethyl ether was added and the condenser was removed. After most of the ammonia had evaporated, water was added and the two-phase system was separated. The aqueous phase was extracted with diethyl ether and the combined ethereal solution was washed with dilute hydrochloric acid and water. After drying over anhydrous magnesium sulfate, the solvent was evaporated under reduced pressure and the cloudy oil which remained showed two spots on thin layer chromatography and hydroxyl absorption in the infrared spectrum (2.92  $\mu$ ). The crude product was subjected to chromic acid oxidation<sup>23</sup> to afford a yellow oil, which was distilled at 60–73° (0.15–0.25 mm.) to provide 2.85 g. of a colorless oil (XLII), higher boiling material being rejected. Thin layer chromatography showed only a single spot: infrared spectrum 5.85 (s) and 4.62  $\mu$  (w); mass spectrum (*m/e* values) 164 (*d*<sub>0</sub>, 4%), 165 (*d*<sub>1</sub>, 92.5%), and 166 (*d*<sub>2</sub>, 3.5%).

*trans-3-Bromo-10-methyldecal-2-one-4 $\alpha$ -d<sub>1</sub>* (XLIII) was synthesized from 128 mg. of the octalone XLII, as

(38) C. Djerassi, D. Marshall, and T. Nakano, *J. Am. Chem. Soc.*, **80**, 4853 (1958).

described in the preparation of the C-4 epimer X, to afford 110 mg. of crystalline material (XLIII), which was recrystallized from aqueous acetone: m.p. 136.5–139.5°; n.m.r., doublet centered at  $\delta$  4.67 and 4.90, *J* = 14 c.p.s.

*Anal.* Calcd. for C<sub>11</sub>H<sub>16</sub>BrDO: C, 53.66; H + D, 7.32. Found: C, 53.64; H + D, 7.14.

*trans-9-Methyl- $\Delta^2$ -octahydronaphthalene-8 $\beta$ -d<sub>1</sub>* (XLIV) was prepared from 2.40 g. of octalone XLII as reported for the synthesis of the epimer VI, to furnish a crude product which when distilled at 0.25 mm. below 55° afforded 1.26 g. of a colorless oil (XLIV): infrared spectrum 4.63  $\mu$  (w); mass spectrum (*m/e* values) 150 (*d*<sub>0</sub>, 4%), 151 (*d*<sub>1</sub>, 93%), and 152 (*d*<sub>2</sub>, 3%).

*trans-1-Methylcyclohexane-1,2-diacetic-6 $\beta$ -d<sub>1</sub> acid* (XLV) was prepared from 1.19 g. of XLIV, as described for the synthesis of the isomer VII, to afford a solid, which when recrystallized from acetone provided 1.02 g. of XLV, m.p. 194–197°.

*trans-8-Methylhydrindan-2-one-7 $\beta$ -d<sub>1</sub>* (XLVI). Catalytic pyrolysis of the diacid<sup>15</sup> XLV (980 mg.), as described in the preparation of *trans-8-methylhydrindan-2-one-7 $\alpha$ -d<sub>1</sub>* (VIII), afforded a crude oil which was distilled at 35–50° (0.10 mm.) to furnish 431 mg. of a yellow oil. Redistillation at 40–50° (0.10 mm.) provided an oil (XLVI) which was shown to be homogeneous by vapor phase chromatography on a 5% diethylene glycol succinate on 60/80 firebrick column at 140°: mass spectrum (*m/e* values) 152 (*d*<sub>0</sub>, 4%), 153 (*d*<sub>1</sub>, 94%), and 154 (*d*<sub>2</sub>, 2%).

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## The Structure of the So-Called "Ethyl Metaphosphate" (Langheld Ester)

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*Phosphorus pentoxide reacts with diethyl ether to form mixtures of polyphosphate esters consisting of bicyclopolyphosphate ester (II), cyclotetrapolyphosphate ester (III), isocyclotetrapolyphosphate ester (IV), and tetrapolyphosphate ester (V). While the presence of reorganization products, especially tripoly- and pentapolyphosphate esters, cannot be unequivocally excluded, the consistency of all the measurements, including the absence of pyrophosphates, would be difficult to maintain if this had occurred to any large extent. The content of the tetrapolyphosphate esters in the mixtures*

*was calculated from <sup>31</sup>P n.m.r. measurements with this assumption. The so-called ethyl metaphosphate (Langheld ester) is a mixture of III (45 to 50%), IV (25 to 36%), and V (14 to 30%). From the selective reaction rates one might expect that the effective reaction sites for dehydration polymerization would be the branched phosphorus atoms (P<sub>b</sub>) found only in compounds II and IV. These particular compounds are the very ones most difficult to produce.*

The product of the reaction of diethyl ether and phosphorus pentoxide,<sup>3</sup> which is usually called ethyl meta-

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(3) K. Langheld, *Ber.*, **43**, 1857 (1910); **44**, 2076 (1911).