7,12-Dihydropleiadenes. VIII. A Transannular 1,5 Hydride Shift Accompanying Synthesis of 7-Alkyl-1,12-(*o*-phenylene)-7,12-dihydropleiadenes by Cyclodehydration[1]

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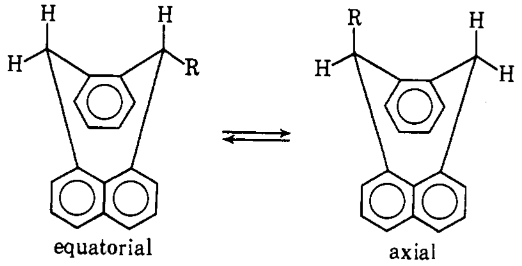
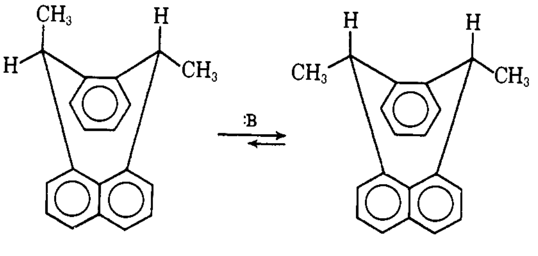
Abstract: 7-Alkyl-12(7H)-pleiadenones react with phenyllithium by direct and conjugate addition paths, the product composition depending on the C_7-alkyl group in the starting ketone. Also, depending on this latter group, both types of products can be converted to 1,12-(*o*-phenylene)-7,12-dihydropleiadenes (with 7-CH_3 or C_2H_5), or 7,12-(*o*-phenylene)-7,12-dihydropleiadenes (with 7-C_6H_5), or undergo transannular 1,5-hydrogen rearrangement (with 7-*i*-C_3H_7). 7-Methyl- and 7-ethyl-1,12-(*o*-phenylene)-7,12-dihydropleiadenes were equilibrated with base and the *cis* isomers found to be more stable than *trans* isomers.

The present investigation was prompted by our earlier finding that simple alkyl groups had remarkably different conformational preferences in 7-alkyl-7,12-dihydropleiadenes.[3]



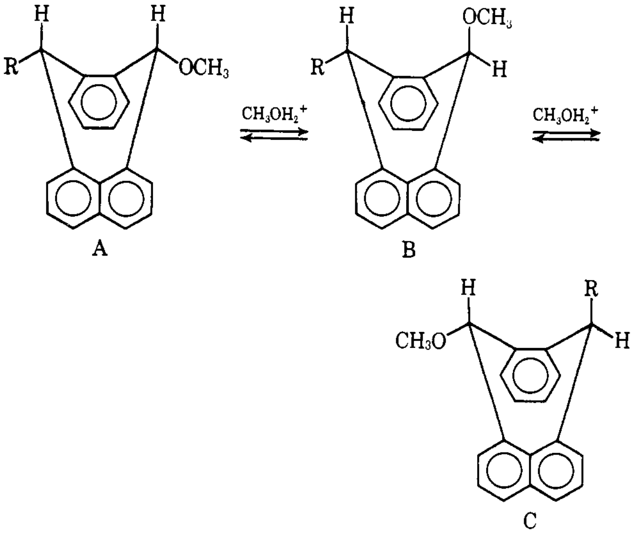
R	$K_{243°}$ ([A]/[E])
CH_3	0.14
C_2H_5	1.1
i-Pr	>20

The above data, derived from analysis of conformer populations, were buttressed by chemical equilibration studies involving flexible, diastereomeric compounds. For example, diequatorial *cis*-7,12-dimethyl-7,12-dihydropleiadene predominated over the *trans* isomer under basic equilibrating conditions,[3] as expected.



$$K_{298°} = \frac{[\text{cis}]}{[\text{trans}]} = 1.85$$

In addition, the methoxy group, which has a slight preference for the axial position in 7,12-dihydropleiadene,[4] could be shown to exercise its usual preference in 7-methyl-12-methoxy-7,12-dihydropleiadene[3] during acidic equilibration in methanol since the transannular *equatorial* methyl group does not sterically interfere with it. On the other hand, the overwhelming axial demand of a 7-isopropyl group required the C_{12}-methoxy group to remain equatorial only.[3]



R	isomeric species present
CH_3	B & A in ~2:1 ratio
i-Pr	C only

We considered it significant to extend these stereochemical studies to polynuclear systems similar to dihydropleiadenes (DHP's). One major motivation for us has been to acquire information on effective steric bulks of common substituents in environments other than the thoroughly studied cyclohexanes[5] which cannot always serve as adequate stereochemical models for other cyclic systems.

In earlier research, we had encountered the facile cyclodehydration of 7-phenyl-7-hydroxy-7,12-dihydro-

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[1] Presented in part at the 152nd National Meeting of the American Chemical Society, Chicago, Ill., Sept 1967.

[2] (a) Alfred P. Sloan Foundation Fellow, 1963–1967. (b) Du Pont Predoctoral Teaching Fellow, 1966–1967.

[3] P. T. Lansbury, A. J. Lacher, and F. D. Saeva, *J. Am. Chem. Soc.*, 89, 4361 (1967).

[4] P. T. Lansbury, J. F. Bieron, and A. J. Lacher, *ibid.*, **88**, 1482 (1966).

[5] E. L. Eliel, N. L. Allinger, S. J. Angyal, and G. A. Morrison, "Conformational Analysis," John Wiley & Sons, Inc., New York, N. Y., 1965, Chapters 2 and 7.

pleiadene[4,6] to 1,12-(*o*-phenylene)-7,12-dihydropleiadene and now intended to prepare simple 7-alkyl derivatives of the parent nucleus. This system is conformationally rigid and incapable of ring inversion. Nevertheless, the conformation of the seven-membered ring in 1,12-(*o*-phenylene)-7,12-dihydropleiadenes is not too dissimilar from analogous dihydropleiadenes, as judged from inspection of models. Hence we undertook the synthesis and stereochemical investigation of isomeric 7-alkyl-1,12-(*o*-phenylene)-7,12-dihydropleiadenes, whose acidic C_{12}-fluorenyl-type protons[7] were expected to provide a simple means for basic equilibration. As described below, we experienced no difficulty in obtaining the 7-methyl and 7-ethyl compounds, but cyclization to provide the 7-isopropyl analog was by-passed in favor of a transannular 1,5-hydride shift, whose elaboration became the major aspect of our efforts.

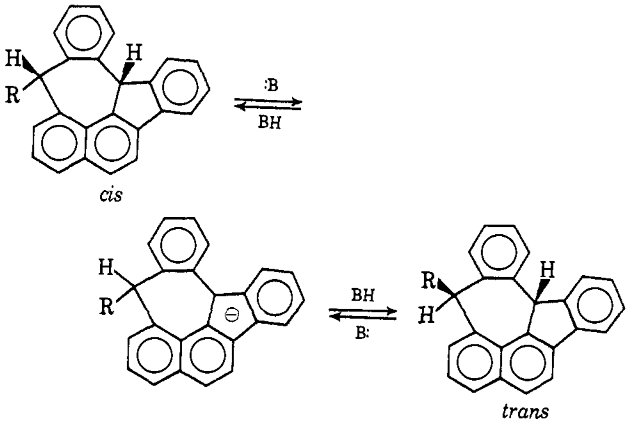
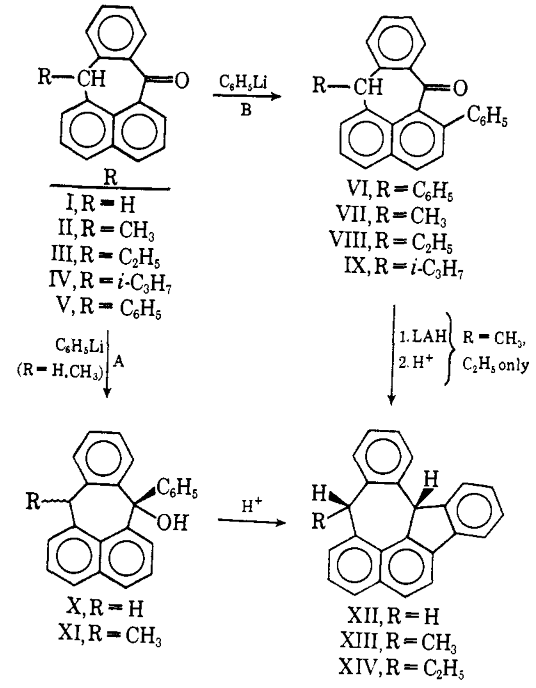


Chart I

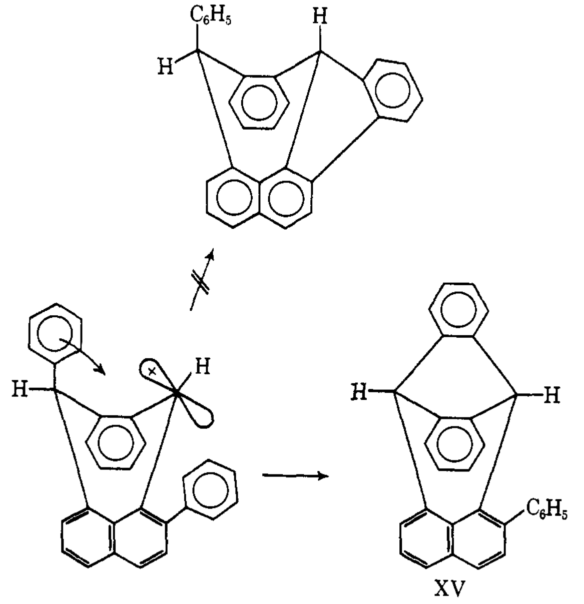


	$\lambda_{max}^{EtOH\,a}$, mμ
XII,	256, 266, 296, 308, 322
XIII,	256, 266, 297, 309, 323
XIV,	257, 267, 298, 310, 323

[a] The 256 and 266-mμ bands are most intense (ε ~30,000–50,000).

Results and Discussion

The reaction of 7(12H)-pleiadenone and several 12-alkyl derivatives[3] (I–V) with phenyllithium proceeded both by direct carbonyl attack (route A in Chart I) and 1,4-conjugate addition[8] (route B, Chart I). The latter process predominates with 12-methyl-7(12H)-pleiadenone and is the exclusive detectable one for larger C_{12} substituents. The 1-phenyl-7-alkyl-12(7H)-pleiadenones (VI–IX) arising from conjugate addition invariably showed shorter wavelength carbonyl stretching bands (~6.0 μ) than their precursors I–V ($\lambda_{C=O}$ ~6.05–6.1 μ), due to out-of-plane bending of the carbonyl group by the *o*-aryl substituent. Reduction of ketones VII and VIII by lithium aluminum hydride and cyclodehydration (trifluoroacetic or formic acids) provided the desired benzofluorenes XIII and XIV. Their structures follow from ultraviolet spectral comparison (see Chart I) with the parent 1,12-(*o*-phenylene)-7,12-dihydropleiadene[4] (XII), which arises *via* route A (as does XIII in part as well). When ketone VI was subjected to the above reduction–cyclization sequence, the hydrocarbon product was not a 1,2-benzofluorene (no uv maxima at ~255 and 265 mμ) but instead possessed the isomeric 7,12-(*o*-phenylene)-7,12-dihydropleiadene structure[9] (XV). This reaction is analogous to the cyclodehydration of 7-phenyl-12-hydroxy-7,12-dihydropleiadene, which gives the parent "triptycene-like" structure,[9] not unexpectedly. The consequences of reduction–cyclization applied to IX were much more unusual and are taken up in detail at a later point, after the stereochemistry of XIII and XIV is dealt with.



XV

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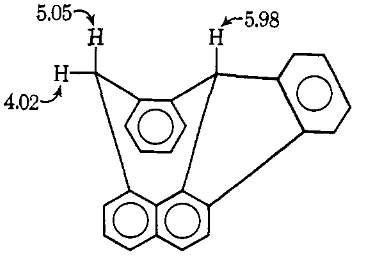
(6) M. P. Cava and W. S. Lee, *Tetrahedron*, 24, 837 (1968). These workers observed the same cyclization in the 1-CH₃ analog.

(7) C. D. Ritchie and R. E. Uschold, *J. Am. Chem. Soc.*, 90, 2821 (1968).

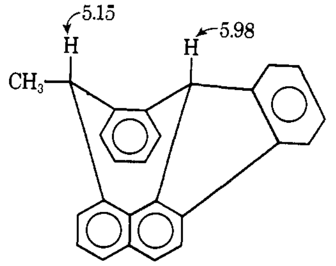
(8) Methyl- and ethyllithiums similarly add conjugatively to C_{12}-alkyl-7(12H)-pleiadenones (A. J. Lacher, unpublished observations); Cava and Lee[6] also obtained some 1,4 addition of methyl Grignard to 1-methyl-7(12H)-pleiadenone.

(9) The parent 7,12-(*o*-phenylene)-7,12-dihydropleiadene was prepared by A. J. Lacher, Ph.D. Dissertation, State University of New York at Buffalo, Buffalo, N. Y., 1967, and had λ_{max}^{EtOH} (log ε): 282 (3.81), 291 (3.9), and 302 mμ (3.83). The model compound, 7-phenyl-7,12-dihydropleiadene, has λ_{max}^{EtOH} (log ε): 278 (3.86), 289 (3.99), and 300 mμ (3.82) (P. T. Lansbury, *J. Am. Chem. Soc.*, 81, 4325 (1959)).

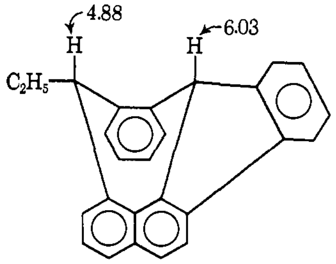
7-Methyl- and 7-ethyl-1,12-(*o*-phenylene)-7,12-dihydropleiadenes (XIII and XIV) can exist as *cis* and *trans* diastereomers and one ideally wants to equilibrate both isomers separately. XIII and XIV were each obtained as single racemates from cyclodehydration (although minor amounts of diastereomer may have been lost in recrystallization) and their stereochemistry was assigned as *cis*. This conclusion is based on the nmr chemical shifts (δ values) of C_7-methine protons in XIII and XIV, which correspond closely to the axial C_7 proton in XII.[4] Additional proof of configuration was gained from noting that the C_7–axial H and C_{12}–H chemical shifts in XII–XIV are relatively constant whereas a distinct transannular deshielding effect on such protons is produced by an axial alkyl group, as in 12-methyl-1,12-(*o*-phenylene)-7,12-dihydropleiadene.



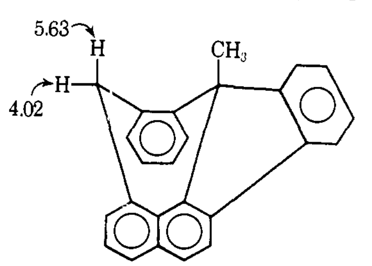
XII



XIII



XIV



The assignments of the C_7-methylene signals in this compound were further verified by observation of a nuclear Overhauser effect (NOE) on the axial C_7–H signal when the methyl group was saturated by a second radiofrequency field.[10] Although we did not secure the pure *trans* isomers of XIII and XIV, we did produce a mixture of the diastereomeric methyl compounds, *cis*- and *trans*-XIII, by kinetic protonation (rapid quenching in cold, dilute hydrochloric acid) of 7-methyl-12-lithio-1,12-(*o*-phenylene)-7,12-dihydropleiadene. The prevalent *trans* isomer (*ca.* 2:1 *trans* and *cis* ratio) showed C_7- and C_{12}-methine signals at 4.52 (quartet, $J \sim 7.5$ Hz) and 6.08 ppm, respectively. The equatorial C_7–H signal in *trans*-XIII is seen to be upfield by 0.63 ppm from the axial C_7–H signal in *cis*-XIII, which is consistent with previous assignments for these diastereomeric protons. Also, as expected the C_{12}–H signal in *trans*-XIII is deshielded by 0.1 ppm, as a consequence of facing the 7-CH_3. When the *cis*:*trans* mixture of XIII was equilibrated with sodium methoxide in methanol and then reisolated, pure *cis*-XIII remained. Likewise, prolonged exposure of XIII as well as XIV with potassium *t*-butoxide in *t*-butyl alcohol–pyridine followed by careful nmr examination of the recovered material showed no detectable amounts of *trans* isomer from either compound. There is no doubt that the latter basic conditions were also more than ample for reversible carbanion formation.[7]

The steric preference of the methyl group in XIII is analogous to the situation in methyl-substituted dihydropleiadenes,[3] and it would now seem appropriate to compare the isopropyl group, with its strong axial preference[3] in the two corresponding derivatives. However, it has already been pointed out that IX did not undergo reduction and subsequent dehydration in the manner of VII and VIII.

When the carbinol derived from IX was treated with acetic acid containing a catalytic amount of sulfuric acid, an immediate deep red color developed, which indicated the conjugated diarylcarbonium ion expected from ionization. This intense coloration, typical for all the carbinols in this research, faded rapidly; work-up afforded 1-phenyl-7-isopropylidene-7,12-dihydropleiadene (XVI) as the major product. Because of restricted conformational inversion,[11] the C_{12} protons of XVI appeared in the nmr as an AB quartet centered at 4.32 ppm ($\Delta\nu_{AB} = 0.38$ ppm, $J_{AB} \simeq 14$ Hz) at probe temperature. The diastereomeric methyl groups in XVI absorb at 1.74 and 1.97 ppm, in good agreement with the corresponding methyl signals at 1.74 and 1.90 ppm in 7-isopropylidene-7,12-dihydropleiadene.[11]

The rearrangement which produces XVI could involve an initial 1,4-dehydration, providing a pleiadene, which would then reprotonate and eliminate, or proceed intramolecularly by a transannular 1,4- or 1,5-hydride shift, followed by proton loss (Chart II). Although 1,4-hydride transfer leads initially to a seemingly more stable cation, the transition state for such a process requires the isopropyl group to take up a highly compressed environment. Such a process would therefore be more likely in the methyl case,[12] but in the event only XIII was formed (*vide supra*). It was decided to resolve this problem by working with the more accessible 7-isopropyl-12-hydroxy-7,12-dihydropleiadene which only lacked the apparently unneeded

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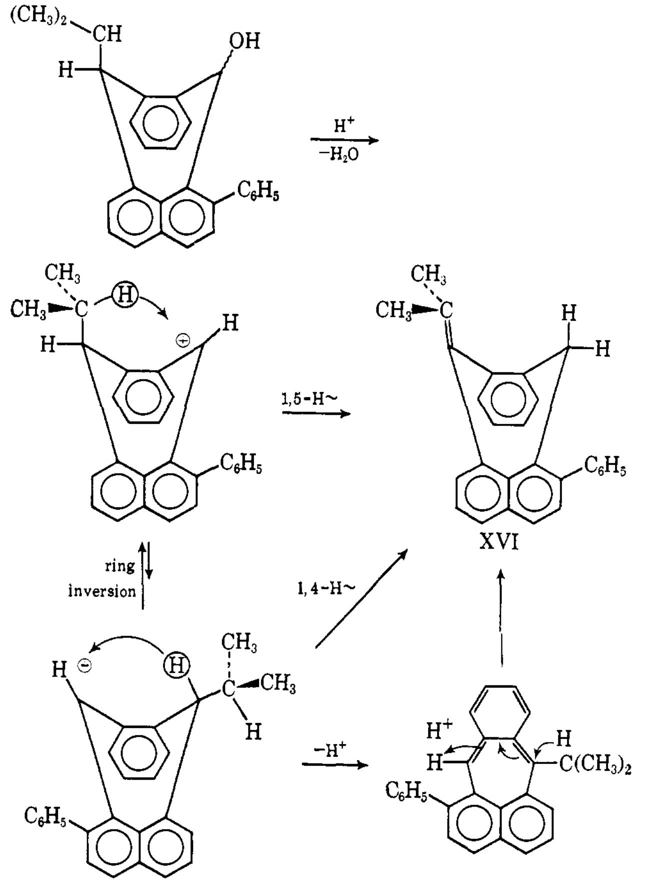
(10) J. G. Colson, P. T. Lansbury, and F. D. Saeva, *J. Am. Chem. Soc.*, 89, 4987 (1968).

(11) P. T. Lansbury, J. F. Bieron, and M. Klein, *ibid.*, 88, 1477 (1966).

(12) The absence of 1,4-hydride transfer, even with 7-methyl-12-hydroxy-7,12-dihydropleiadene, is surprising in view of the facile *base*-induced 1,4 shift in 7-hydroxy-12(7H)-pleiadenones (P. T. Lansbury and F. D. Saeva, *ibid.*, 89, 1890 (1967)).

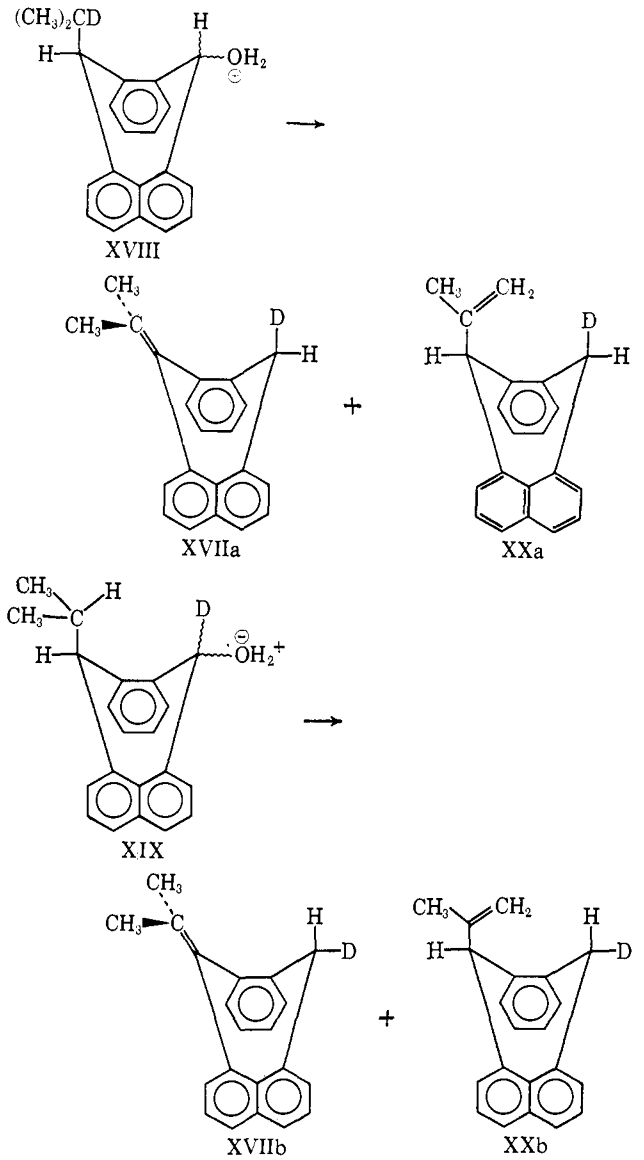
Chart II



1-phenyl group and whose expected rearrangement product, 7-isopropylidene-7,12-dihydropleiadene (XVII), was already known.[11]

Deuterium was chosen as an isotopic label to determine if the rearrangement leading to XVII was intramolecular and, if so, which hydride of the two logical candidates migrated. Accordingly, isopropyl-*α-d* *p*-toluenesulfonate was allowed to react with 7-lithio-7,12-dihydropleiadene[3] to produce 7-(isopropyl-*α-d*)-12-hydroxy-7,12-dihydropleiadene (XVIII) after chromic acid oxidation and $LiAlH_4$ reduction. Similarly, $LiAlD_4$ reduction of IV incorporated deuterium at the migration terminus (*i.e.*, XIX). Brief treatment (50–60° for 30 min) of XVIII and XIX with acetic acid–sulfuric acid followed by careful work-up clearly showed that an intramolecular 1,5-hydride (or deuteride) shift was the path by which rearrangement takes place.[13] The initially colored diaryl carbonium ion (λ_{max} 550 mμ) apparently rearranges to the colorless *t*-alkyl cation which loses a β proton in each of the two possible ways, producing XVII and XX in a 3:1 ratio (kinetic control). More strenuous conditions (*e.g.*, refluxing trifluoroacetic acid) convert XX entirely to the more stable XVII (Chart III). The partial nuclear magnetic resonance spectra of product mixtures of each reaction are shown in Figure 1. Peak assignments due to XVII and XX were verified by subsequent chromatographic separation of both mixtures. The equatorial C_{12} protons in XVIIa and XXa are both at 3.68 ppm (as revealed by integration of this peak area) whereas

Chart III



the axial C_{12} protons in XVIIb and XXb appear at 4.86 and 5.17 ppm, respectively. These assignments are entirely consistent with previous findings on the relative chemical shifts of axial and equatorial C_7 and C_{12} protons in DHP's[11] and are confirmed by comparing with authentic samples prepared as described below.

Clearly, the migrating hydrogen (or deuterium) from the isopropyl group occupies an axial position at C_{12} in the product. Authentic XVIIa was prepared earlier by mild axial deuteration of XVII with potassium *t*-butoxide–dimethyl-d_6 sulfoxide[11] whereas XVIIb arose from analogous axial protonation of XVII containing two deuteriums at C_{12}.[14] The nmr spectra of these specifically monodeuterated derivatives are identical with the pertinent peaks (from XVIIa and b) shown in Figure 1, and do not change during several days at *ca.* 35° because of the exceedingly slow inversion rate.[15]

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(13) For other examples of 1,5-hydride shifts, see R. K. Hill and R. M. Carlson, *J. Am. Chem. Soc.*, 87, 2772 (1965), and references cited therein; also A. C. Cope, M. Martin, and M. McKervey, *Quart. Rev.* (London), 20, 119 (1966).

(14) M. Klein, unpublished results patterned after findings in ref 11.

(15) It was possible to measure the rates of "racemization" of XVIIa and b, which are diastereomeric only by virtue of C_{12}–D, at 120–140° by monitoring the changing peak areas of the appropriate C_{12}-proton signals by nmr. First-order rate constants for the "diasteromeric" enantiomers obtained from the early part of the racemization runs were identical within the rather large experimental error, which arises

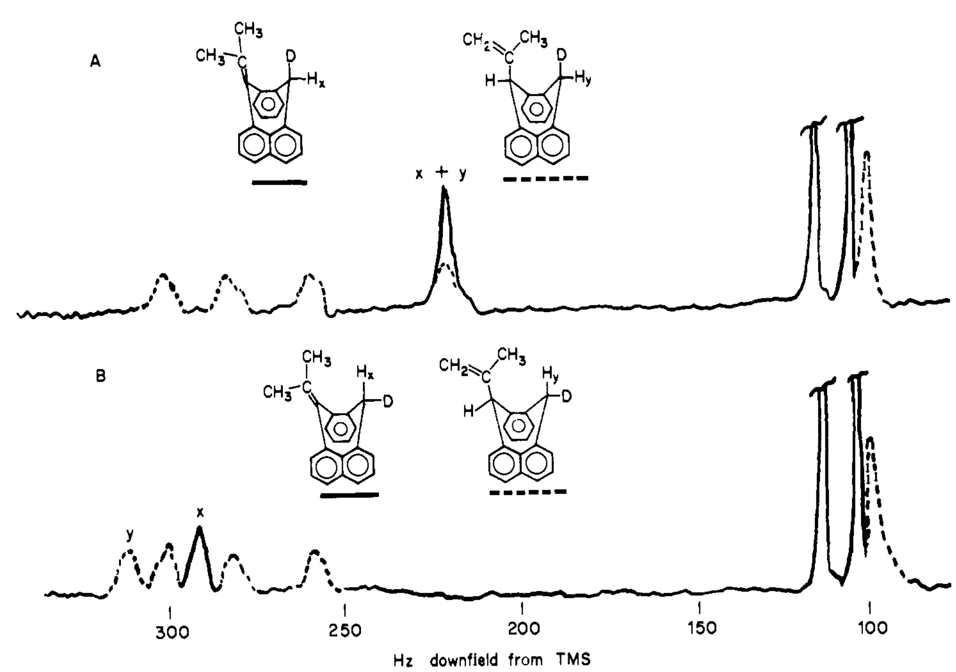
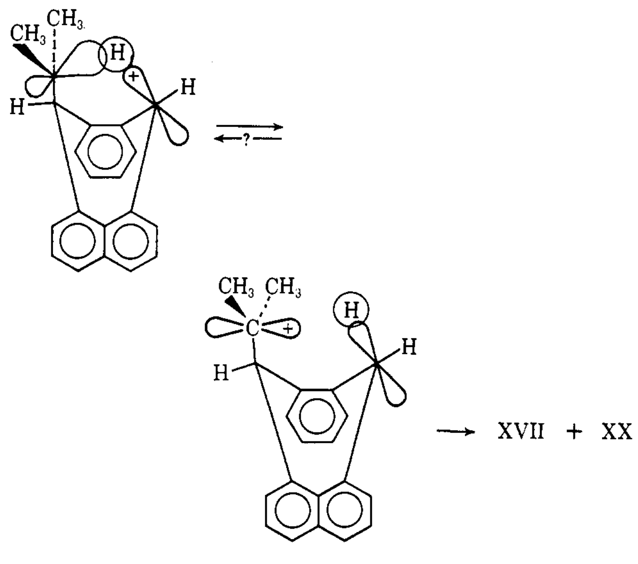


Figure 1. Partial nmr spectra of 1,5-hydride rearrangement products (in $CDCl_3$): A, from XVIII; B, from XIX.

Since XVII has a high inversion barrier amounting to *ca.* 31 kcal/mol at 130°, it is understandable that hydrogen isotope position exchange at C_{12} does not occur to any substantial extent under the rearrangement conditions.

Carbonium ion reactions of 7-isopropyl-12-hydroxyl-7,12-dihydropleiadene (XXI) need not always lead to 1,5-hydride rearrangment. For example, mild methanolysis leads to unrearranged[16] *trans*-7-isopropyl-12-methoxydihydropleiadene, whose preferred conformation has been elucidated previously[3] by nmr. Furthermore trifluoroacetolysis of 7-isopropyl-12(7H)-pleiadenone, wherein the conjugate acid of the ketone is undoubtedly present, results only in recovered starting material.

It remains to comment briefly on the seemingly unfavorable 1,5-hydride rearrangement of XVIII (and XIX), in which a relatively stable diaryl cation gives way to a *t*-alkyl cation of higher potential energy. We are currently engaged in further kinetic studies of the actual rearrangement step (which may be reversible) before which meaningful comments are perhaps premature. However it appears that the final product, which has one trigonal and one tetrahedral carbon at C_7 and C_{12}, has less steric compression energy than the reactant, in which both of these atoms are tetrahedral. Hence, decreased bow–stern and *peri* interactions may be providing the observed driving force, in spite of the relative carbonium ion energies. Furthermore the actual hydride shift is probably not handicapped by an unfavorable ΔS^* since the initial carbonium ion has a preferred conformation from which hydride shift requires essentially no restricted bond rotations in achieving the transition state. Thus only enthalpy factors affect the rearrangement rate in a major way.



Experimental Section[17]

The syntheses of the following precursors have been reported previously: 7-methyl, 7-ethyl-, and 7-isopropyl-12(7H)-pleiadenones,[3] and 7-phenyl-12(7H)-pleiadenone.[18]

Preparation of *cis*-7-Methyl-1,12-(*o*-phenylene)-7,12-dihydropleiadene (XIII). Excess ethereal phenyllithium was slowly added to a

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from measuring two peaks of substantially different areas. Typical data are: $k_{393°} \simeq 3.8 \times 10^{-6}$ sec^{-1}, $k_{403°} \simeq 8.6 \times 10^{-5}$ sec^{-1}, $k_{413°} \simeq 3.5 \times 10^{-4}$ sec^{-1}; $\Delta F^*_{403°} \simeq 31$ kcal/mol; M. Klein unpublished results.

(16) This fact led us to react XXI with *ca.* 0.5 molar equiv of *l*-menthol with the hope that a predominance of one of the diasteromeric *l*-menthyl ethers would arise. The ether thus obtained was separated from unreacted carbinol by alumina chromatography and rearranged in acid under the usual conditions. There arose a quantity of optically active 7-isopropylidenedihydropleiadene, $[\alpha]^{27}D \simeq 13°$, whose optical rotation did not diminish during several days at room temperature. We do not yet know the degree of optical purity or absolute configuration of this material (F. D. Saeva, unpublished results).

(17) Melting points are uncorrected. Infrared spectra were obtained on a Beckmann IR-5A spectrometer using Nujol mulls or neat films between sodium chloride plates. Ultraviolet spectra were recorded on a Perkin-Elmer Model 202 spectrometer. Nmr spectra were obtained using Varian A-60 or HA-60 spectrometers in chloroform-*d* solutions containing tetramethylsilane as internal standard. Elemental analyses were performed by Dr. Alfred Bernhardt, Mulheim, Germany. Petroleum ether for column chromatography was the 30–60° boiling range.

(18) P. T. Lansbury, *J. Am. Chem. Soc.*, 81, 935 (1959).

tetrahydrofuran solution of II (*ca.* 0.5–1.0 g) followed by stirring overnight under nitrogen. After hydrolysis with aqueous ammonium chloride solution, the organic phase was washed with aqueous sodium hydroxide and with brine and then dried over magnesium sulfate. Upon removal of solvent by flash evaporation, the crude residue was chromatographed over alumina, using 1:4 ether–petroleum ether as eluent. The conjugate addition product VII, mp 151–153° (ethanol), was eluted initially in *ca.* 10% yield. Pertinent infrared bands (in Nujol mull) appeared at 6.01, 7.83, 11.10, 11.72, 13.20, and 14.23 μ.

Anal. Calcd for $C_{25}H_{18}O$: C, 89.8; H, 5.4. Found: C, 90.2; H, 5.6.

The carbinol XI followed VII off the column (*crude* yield *ca.* 60%) and was recrystallized from ethanol, mp 231–235°; infrared bands (Nujol) appeared at 2.88, 11.97, 13.03, 13.34, 14.20, and 14.38 μ.

Heating XI in acetic acid–sulfuric acid for several minutes (formic acid containing a little polyphosphoric acid also sufficed) resulted in bleaching of the initially red solution. Hydrolysis in ice water, followed by ether extraction, sodium carbonate wash, and drying over magnesium sulfate in the usual manner, produced crude XIII from which pure material was obtained in 40% yield by recrystallization from ethanol, mp 244–255°; ultraviolet and nmr data for XIII are presented in the Discussion.

Anal. Calcd for $C_{25}H_{18}$: C, 94.3; H, 5.7. Found: C, 94.0; H, 6.0.

Alternatively, XIII could be prepared from ketone VII (above) by reduction with excess ethereal lithium aluminum hydride (LAH) (30-hr reflux). Standard hydrolysis and work-up procedures produced an oily product whose infrared spectrum (neat) showed hydroxyl absorption at 2.9 μ and no carbonyl band. This material was cyclized as above in acetic acid containing a catalytic quantity of sulfuric acid to give XIII, mp 243–244°, in 42% yield (after alumina chromatography with petroleum ether elution and recrystallization); this product gave no mixture melting point depression when mixed with XIII prepared above and the two samples had identical spectral properties.

Preparation of *cis*-7-Ethyl-1,12-(*o*-phenylene)-7,12-dihydropleiadene (XIV). As above, a fourfold excess of phenyllithium in 1:4 hexane–benzene was slowly added to 1.3 g of ketone III in 1:4 ether–tetrahydrofuran at 0° and under nitrogen. After 12 hr at room temperature, the reaction mixture was hydrolyzed and worked up in the usual manner. The crude product was subjected to chromatography over alumina and, after elution of some biphenyl with petroleum ether, the conjugate addition product VIII eluted with 1:4 ether–petroleum ether. Recrystallization from ethanol gave off-white crystals, mp 144–147°, in 57% yield; the infrared spectrum (Nujol) showed absorption at 5.98, 11.86, 13.06, 13.18, 14.30, and 14.58 μ.

Reduction of VIII with excess ethereal lithium aluminum hydride (24-hr reflux) provided crude carbinol (by infrared analysis) which was cyclodehydrated in refluxing acetic acid–sulfuric acid (5 min required to bleach the red solution). Quenching in ice water followed by work-up and alumina chromatography led to pure XIV (by petroleum ether elution) having mp 214–215° (colorless needles from ethanol), in 50% yield. The infrared spectrum (Nujol) had bands at 11.78, 11.92, 12.22, 12.96, 13.32, 13.58, 13.86, and 14.00 μ; the confirmatory ultraviolet and nmr spectral data are presented in the Discussion.

Anal. Calcd for $C_{26}H_{20}$: C, 93.9; H, 6.1. Found: C, 39.9; H, 6.3.

Attempted Preparation of 7-Isopropyl-1,12-(*o*-phenylene)-7,12-dihydropleiadene. Following the synthetic procedures used to acquire XIII and XIV, excess phenyllithium in 4:1 benzene–hexane was added to ketone IV (*ca.* 2 g) in ether–THF. After the usual work-up and chromatographic separation, there resulted 0.37 g (15%) of pure 1-phenyl-7-isopropyl-12(7H)-pleiadenone (IX), mp 188–190° (ethanol), showing infrared absorption (Nujol) at 5.95, 11.98, 13.11, 13.23, 13.37, and 14.34 μ.

Anal. Calcd for $C_{27}H_{12}O$: C, 89.5; H, 6.1. Found: C, 88.9; H, 6.3.

Ketone IX (0.3 g) was reduced with excess lithium aluminum hydride in 1:4 ether–THF (14 hr at room temperature), then hydrolyzed and worked up. The crude carbinol (by ir analysis) was dissolved in 50 ml of acetic acid and 10 ml of acetic anhydride and one drop of H_2SO_4 were added. The bright red solution bleached within 10 sec and the solution was refluxed an additional 15 min before quenching on ice and work-up. Alumina chromatography of the crude oily product led to 35 mg (30%) of a hydrocarbon (eluted with petroleum ether), mp 169–170° (ethanol), showing no uv maxima at 250–270 mμ and infrared bands at 11.97, 13.06, 13.63, 14.16, and 14.35 μ; nmr analysis (see Discussion) indicated this product to be 1-phenyl-7-isopropylidene-7,12-dihydropleiadene (XVI). Subsequently, further elution with petroleum ether provided a small amount of noncrystalline hydrocarbon (*ca.* 10 mg) showing uv maxima at 256 and 265 mμ, which may be the originally sought benzofluorene.

Preparation of 1-Phenyl-7,12-(*o*-phenylene)-7,12-dihydropleiadene (XV). Addition of excess phenyllithium to 0.34 g of ketone V in ether–THF (7-hr reaction at room temperature) followed by work-up and alumina chromatography gave 0.14 g (32%) of 1,7-diphenyl-12(7H)-pleiadenone (VI), mp 228–230°, with infrared bands at 5.98, 7.97, 9.97, 11.80, 11.96, 13.20, 13.55, and 14.36 μ.

Anal. Calcd for $C_{30}H_{20}O$: C, 90.9; H, 5.1. Found: C, 90.4; H, 5.1.

VI (75 mg) was reduced by excess LAH and the oily carbinol (by infrared) dissolved in 30 ml of hot acetic acid. Addition of one drop of sulfuric acid produced the usual red color, followed by rapid bleaching. Work-up and recrystallization from ethanol gave 35 mg (50%) of XV, mp 268–270°, whose ultraviolet spectrum is discussed in ref 8.

Anal. Calcd for $C_{30}H_{20}$: C, 94.7; H, 5.3. Found: C, 94.9; H, 5.3.

The nmr spectrum of XV showed one-proton methine singlets at 5.48 (C_{12}–H) and 5.12 ppm (C_7–H). These assignments are verified by noting the absence of the low-field C_{12}–H signal in XV-C_{12}-*d*, obtained from lithium aluminum *deuteride* reduction of VI and subsequent cyclodehydration.

Rearrangement of 7-Isopropyl-12-hydroxy-7,12-dihydropleiadene and the Methyl Ether. When either 7-isopropyl-12-hydroxy-7,12-dihydropleiadene[3] or the methyl ether[3] (usually *ca.* 0.2–0.3-g scale) was dissolved in 20–30 cc of acetic acid and one drop of sulfuric acid added, a bright red solution resulted (λ_{max} 550 mμ). After 30 min at 50–60°, the nearly colorless solution was quenched in ice water and worked up. Alumina chromatography of the crude product (*ca.* 90% yield of dehydrated material) achieved a separation into *ca.* three parts of 7-isopropylidene-7,12-dihydropleiadene,[11] mp 103–104°, which was first eluted with benzene–petroleum ether (5:95), and one part of 7-isopropenyl-7,12-dihydropleiadene (XX), mp 125–126°, which was next eluted with benzene–petroleum ether (10:90).

Anal. Calcd for $C_{20}H_{18}$: C, 93.0; H, 7.0. Found: C, 92.7; H, 6.9.

The constitution of XX follows from the nmr spectrum: an AB spectrum, due to C_{12}–CH_{21} centered at 4.42 ppm ($\Delta\nu_{AB}$ = 1.5 ppm, $J_{AB} \simeq$ 14.5 Hz), the C_7 proton at 4.29 (broad "singlet"), the isopropenyl methylene protons at 4.67 and 4.98 (broad multiplets due to allylic long-range coupling), and the methyl signal at 1.67 ppm (broad multiplet). The isopropenyl isomer XX was cleanly isomerized to 7-isopropylidene-7,12-dihydropleiadene (XVII) by brief refluxing in trifluoroacetic acid or more prolonged and vigorous acetolysis than the above-described procedure which gives kinetic control.

The experiments using deuterium as a tracer for mechanistic purposes were carried out in the same manner. Thus, lithium aluminum hydride reduction of 7-(isopropyl-α-*d*)-12(7H)-pleiadenone (IV-d_1) (prepared from 2-propanol-2-*d* obtained from Merck Sharp and Dohme, Ltd. and $\geq$98% isotopically pure) gave XVIII whose acetolysis gave a mixture of XVIIa and XXa, whose nmr spectrum (Figure 1) showed both isomers to possess axial C_7–D. In a parallel experiment, lithium aluminum deuteride (Alpha Inorganics) reduction of IV produced carbinol XIX bearing the label at the carbinyl position; rearrangement produced a 3:1 mixture of XVIIb and XXb. Again nmr analysis (Figure 1 and Discussion) confirmed qualitatively and semiquantitatively that both isomers contained equatorial C_7–D. It is of course possible that up to *ca.* 5% shuffling of the tracer between axial and equatorial positions (due to ring inversion) occurred and was not detectable by nmr.

Equilibration Studies of 7-Alkyl-1,12-(*o*-phenylene)-7,12-dihydropleiadenes. A. A 100-mg sample of XIII dissolved in ether was treated with an equivalent quantity of *n*-butyllithium in hexane, under an argon atmosphere. The colored solution was quenched in ice-cold 3 *N* HCl and worked up. Nmr examination of the total recovered hydrocarbon revealed a 1:2 *cis–trans* mixture (see Discussion) from kinetic protonation. This material was then stirred for 24 hr at room temperature with sodium methoxide in methanol and reisolated; nmr now indicated that only pure XIII was present.

B. Samples of XIII and XIV (*ca.* 100 mg each) were kept for *ca.* 20 hr at room temperature in nitrogen-flushed sealed tubes with potassium *t*-butoxide in *t*-butyl alcohol–pyridine. After hydrolysis and careful work-up to ensure isolation of all hydrocarbon product, nmr analysis showed signals only of starting compounds and no evidence for the *trans* stereoisomers.

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Cycloaddition. X. Reversibility in the Biradical Mechanism of Cycloaddition. Tetrafluoroethylene and 1,1-Dichloro-2,2-difluoroethylene with 2,4-Hexadiene

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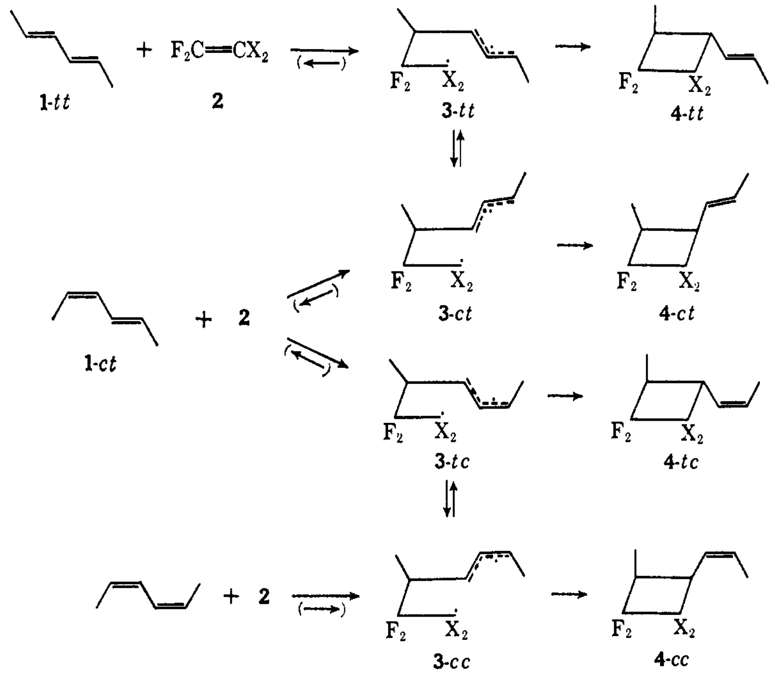
Abstract: The four stereoisomeric cyclobutanes from thermal cycloaddition of 1,1-dichloro-2,2-difluoroethylene ("1122") to the stereoisomeric 2,4-hexadienes[1] at 80° have been isolated by preparative vapor phase chromatography and their configurations as previously assigned have been confirmed by nuclear magnetic resonance. Tetrafluoroethylene at 120° adds to *trans,trans*-2,4-hexadiene to yield only the two stereoisomeric *trans*-propenylcyclobutanes in a *trans/cis* ratio in the ring of 4.2, and with no isomerization of the recovered diene. At this same temperature the addition of 1122 to *trans,trans*-2,4-hexadiene is attended by isomerization of the diene and formation of minor amounts of *cis*-propenylcyclobutanes along with major amounts of the *trans*-propenylcyclobutanes. The isomerization is interpreted as due to reversal of the initial biradical formation, which may occur after rotation in the biradical. The similar amounts of loss of configuration with tetrafluoroethylene and 1122 lead to the suggestion that the rate of ring closure is controlled, not by the rate constant of radical–radical combination, but by the rate of rotations about the three single bonds of the biradical to bring it into a conformation suitable for ring closure from an original distribution of non-*cis* conformations.

The thermal addition of 1,1-dichloro-2,2-difluoroethylene ("1122") to the geometrical isomers of 2,4-hexadiene yields mixtures of cyclobutanes of identical orientation but differing in configuration at the ring.[1] The proportions of the products correspond to incomplete rotational equilibration of an intermediate biradical **3** (Chart I); from the relative amounts of **4**-*tt* and **4**-*ct* from **1**-*tt* and **1**-*ct* when X = Cl, it was possible to conclude that **3**-*ct* is converted by internal rotation into **3**-*tt* with a rate constant ten times that with which it closes to **4**-*ct*. The same figure could be arrived at by using the **4**-*tc*/**4**-*cc* ratios from **1**-*ct* compared to **1**-*cc*.

Chart I



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[1] L. K. Montgomery, K. Schueller, and P. D. Bartlett, *J. Am. Chem. Soc.*, **86**, 622 (1964).

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