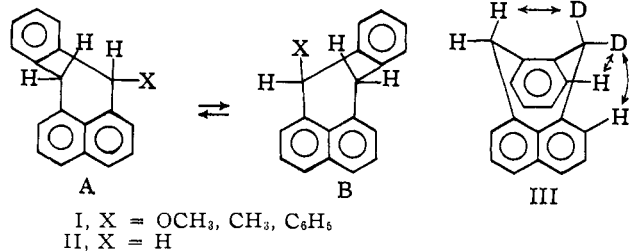


Barriers to Inversion of 7,12-Dihydropleiadenes

Sir:

We wish to report measurements of the inversion barrier separating the folded conformations of several 7,12-dihydropleiadenes by low temperature n.m.r. measurements,¹ which show that this barrier is too low to permit the isolation of diastereomeric conformers² (e.g., I). In addition, the rates of inversion of 7,12-dihydropleia-



dene (II) and 7,12-dihydropleiadene-7,7-*d*₂ (III) have been determined in the search for a steric isotope effect.³

The inversion rates for compounds II-VI were studied⁴ in the temperature range from 40 to -40°. In

using the relationship $k = \pi\delta\omega/\sqrt{2}$ at T_c ,⁷ and the Eyring equation from transition-state theory. In the case of V and VI, the acetate and methoxy methyl signals, which gave symmetrical doublets at low temperature, were used to calculate ΔF^* . Again, the chemical shift differences most likely arise from ring-current effects.⁵

Within experimental error, the inversion barriers in II and III are identical. If the size difference between protium and deuterium were significant,⁸ reduced "bow-stern" and *peri* H-D steric interactions (compared with H-H) in the nonplanar ground state molecules of III should have raised the barrier between enantiomeric conformers, since the planar transition states are less sterically compressed in these respects. Using the Arrhenius equation and E_a calculated for II (14 kcal./mole) by the Piette and Anderson fast-exchange approximation,⁶ it can be shown that T_c should be 2° higher for III than for II if $k_H/k_D = 1.2$ (assuming that the maximum chemical shifts between the nonequivalent protons in II and III are equal, as observed). Clearly the absence of such a detectable change in T_c indicates that if any steric isotope effect

TABLE I
INVERSION BARRIERS IN 7,12-DIHYDROPLEIADENES^a

	II	III	IV	V	VI
T_c , °C.	8°	8°	40°	23°	7°
$\delta\omega$, c.p.s.	72	72	45	18.5	16
ΔF^* , kcal/mole	13.5	13.5	15.4	15.2	14.3

^a T_c and $\delta\omega$ were determined to within $\pm 1^\circ$ and ± 1 c.p.s., respectively, making the maximum error in $\Delta F^* \pm 0.06$ kcal./mole.

hydrocarbons II-IV, the C-7- and C-12-methylene protons appear as a sharp single peak under fast exchange conditions. The low temperature signals are AB quartets ($J_{AB} = 15$ c.p.s.) with large chemical shifts that arise from ring-current effects⁵ on the axial and equatorial protons, the latter lying in the deshielding region of both aromatic rings. Given below are pertinent data from which ΔF^* values were calculated,⁶

(1) Cf. (a) F. A. L. Anet and M. Ahmad, *J. Am. Chem. Soc.*, **86**, 119 (1964); (b) A. T. Bottini and J. D. Roberts, *ibid.*, **80**, 5203 (1958); (c) K. G. Untch and R. J. Kurland, *ibid.*, **85**, 346 (1963); (d) G. Claesson, G. Androes, and M. Calvin, *ibid.*, **83**, 4357 (1961); (e) F. R. Jensen, D. S. Noyce, C. H. Sederholm, and A. J. Berlin, *ibid.*, **84**, 386 (1962); (f) F. A. L. Anet and J. S. Hartman, *ibid.*, **85**, 1204 (1963).

(2) P. T. Lansbury, *ibid.*, **81**, 4325 (1959).

(3) (a) K. Mislow, R. Graeve, A. J. Gordon, and G. H. Wahl, Jr., *ibid.*, **86**, 1199 (1963); (b) L. Melander and R. E. Carter, *ibid.*, **86**, 295 (1964); (c) V. H. Raaen, T. K. Dunham, D. D. Thompson, and C. J. Collins, *ibid.*, **85**, 3497 (1963); (d) E. A. Halevi in "Progress in Physical Organic Chemistry," Vol. I, Interscience Publishers, New York, N. Y., 1963, p. 109.

(4) All spectra were recorded on a Varian A-60 spectrometer equipped with a variable temperature probe and a Model A-6040 temperature controller. The compounds were run in CDCl₃ solution with tetramethylsilane and chloroform as internal standards. Several series of measurements were made over the entire temperature range for each compound and at least four determinations of coalescence temperatures with readings made at 1° intervals above and below T_c . Chemical shifts are given in c.p.s. downfield from tetramethylsilane.

(5) (a) D. Y. Curtin, C. G. Carlson, and C. G. McCarty, *Can. J. Chem.*, **42**, 565 (1964); (b) D. J. Cram and M. Goldstein, *J. Am. Chem. Soc.*, **86**, 1066 (1963); (c) J. S. Waugh and R. W. Fessenden, *ibid.*, **79**, 846 (1957); (d) C. E. Johnson and F. A. Bovey, *J. Chem. Phys.*, **29**, 1012 (1958).

(6) Calculations of E_a and ΔS by various approximations [L. H. Piette and W. A. Anderson, *ibid.*, **30**, 899 (1959); M. Takeda and E. O. Stejskal, *J. Am. Chem. Soc.*, **82**, 25 (1960)] gave inconsistent results which probably arise not from experimental error but from the fact that the exchanging

is operative, it is less than 1.2. Other kinetic investigations of steric isotope effects have also turned up small values of k_H/k_D when steric compression effects in transition states may change with isotopic substitution.^{3a-c} In our case, any rate differences would arise mainly from *ground-state* steric effects, which admittedly are not as serious as in other systems that have been studied.^{3a}

The observed effect of placing methyl groups at positions *peri* to the C-7- and C-12-methylene groups (e.g., IV) on ΔF^* for inversion cannot yet be rationalized satisfactorily.

We are presently extending our studies of rotational barriers in 7,12-dihydropleiadenes and related systems, as well as the conformational preference of 7-substituted and 7,12-disubstituted derivatives. The results will be presented in the full paper, together with syntheses of the compounds used.⁹

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protons are spin-coupled to each other. This problem will be discussed in the full paper.

(7) H. S. Gutowsky and C. H. Holm, *J. Chem. Phys.*, **25**, 1228 (1956).

(8) A. R. Ubbelohde, *Trans. Faraday Soc.*, **32**, 525 (1936).

(9) Correct carbon and hydrogen analyses were obtained for all new compounds and their n.m.r. and ultraviolet spectra are in accord with the proposed structures.

are due to Mr. Dick Johnson and his associates in the University of Illinois Spectroscopy Laboratory for generous and excellent technical assistance.

(10) Alfred P. Sloan Foundation Fellow.

(11) National Science Foundation Pre-Doctoral Fellow, 1962-1964.

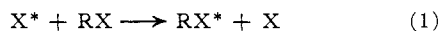
DEPARTMENT OF CHEMISTRY PETER T. LANSBURY¹⁰
STATE UNIVERSITY OF NEW YORK AT BUFFALO
BUFFALO 14, NEW YORK JOSEPH F. BIERON¹¹

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The Stereochemistry of the Replacement of Chlorine Atoms in Alkyl Halides by Chlorine-38 Activated in the (n,γ) Process¹

Sir:

Radioactive halogen species formed by the (n,γ) nuclear reaction were the subjects of most of the initial studies of hot atom chemistry² and have been extensively studied since.^{3,4} The observation of organic "retention" of radioactivity following neutron irradiation is an example of the formal replacement of the halogen atom in an alkyl halide by a radioactive halogen, as in eq. 1.³⁻⁵



The observation of this reaction inspired the early "billiard-ball" theory of hot atom reactions,⁶ and its understanding is of fundamental importance to the recoil chemistry of the halogens.

Despite the large number of experiments reported previously for various halogen isotopes, no information has been available on the stereochemistry of reaction 1.⁷ Complete resolution of a racemic mixture into pure *d* and *l* components in 1 or 2 hr. was not an inviting prospect, so our experiments were conducted with chlorinated molecules containing two asymmetric carbon atoms, the *meso* and *dl* forms of 2,3-dichlorobutane. The *meso* and *dl* forms can be readily separated from one another by gas chromatography, utilizing a 15-ft. column of tritoyl phosphate on firebrick, operated at 100° (retention times: *meso*, 62 min.; *dl*, 73 min.). The halogen isotope studied was Cl³⁸ ($t_{1/2}$ = 37 min.) created by the (n,γ) reaction on the Cl³⁷ isotope contained in the target molecule.

The *meso* and *dl* forms of 2,3-dichlorobutane were prepared by the low temperature addition of Cl₂ to the *cis* and *trans* forms of butene-2, respectively.⁸ The original preparations were 99% (*meso*) and 95% (*dl*) stereospecific, and needed no further purification after the first experiments showed the trend of the results. Irradiation of *meso*-2,3-dichlorobutane in the liquid phase at 20° results in the formation of Cl³⁸

(1) This research has been supported by A.E.C. Contract No. AT-(11-1)-407.

(2) L. Szilard and T. A. Chalmers, *Nature*, **134**, 462, 494 (1934).

(3) J. E. Willard, "Chemical Effects of Nuclear Transformations," Vol. 1, International Atomic Energy Agency, Vienna, 1961, p. 215.

(4) I. G. Campbell, "Advances in Inorganic and Radiochemistry," Vol. 5, Academic Press, Inc., New York, N. Y., p. 135.

(5) The charge states involved in reaction 1 are not unequivocally known, and no implication is intended that the reacting species is necessarily uncharged (see ref. 3).

(6) W. F. Libby, *J. Am. Chem. Soc.*, **62**, 1930 (1940); **69**, 2523 (1947).

(7) The stereochemistry of the replacement of H by recoil T has been investigated in several experiments with the consistent result that the substitution is accompanied by retention of configuration at an asymmetric carbon atom. See M. Henchman and R. Wolfgang, *J. Am. Chem. Soc.*, **83**, 2991 (1961), for the gas phase results with *sec*-butyl alcohol; and J. G. Kay, R. P. Malsan, and F. S. Rowland, *ibid.*, **81**, 5050 (1959), for experiments with crystalline L-(+)-alanine.

(8) H. J. Lucas and C. W. Gould, Jr., *ibid.*, **63**, 2541 (1941).

labeled *meso*- and *dl*-2,3-dichlorobutane in the approximate ratio 1.0:0.39 ± 0.02, as shown in Table I. Experiments with *dl*-2,3-dichlorobutane showed a similar 1.0:0.40 ± 0.02 ratio of Cl³⁸ labeled target molecule to labeled diastereomer. Both the absolute yields of the labeled diastereomers and their yield ratio were essentially unaffected by the presence or absence of free-radical scavengers. The absolute yields in per cent of total Cl³⁸ are in the 3-10% range observed previously for RCl³⁸ from RCl in a variety of systems.^{3,9}

TABLE I

YIELDS OF Cl³⁸-2,3-DICHLOROBUTANES FROM (n,γ) REACTION ON *meso*- OR *dl*-2,3-DICHLOROBUTANE

Conditions Phase, temp. (°C.), scavenger	Relative yield ^a Cl ³⁸ - <i>meso</i> /Cl ³⁸ - <i>dl</i>
Target: <i>dl</i> -2,3-Dichlorobutane	
Liquid, 20, none	0.41 ± 0.02
Liquid, 20, DPPH ^b	0.38 ± 0.02
Liquid, 20, I ₂ ^c	0.36 ± 0.04
Liquid, -56, DPPH	0.65 ± 0.02
Solid -78, none	0.95 ± 0.03
Solid -78 ^d	0.99 ± 0.02
Solid -114 ^d	1.00 ± 0.03
Phase, temp., scavenger	
Target: <i>meso</i> -2,3-Dichlorobutane	
Liquid, 20, none	0.41 ± 0.02
Liquid, 20, DPPH	0.36 ± 0.02
Liquid, 20, I ₂ ^c	0.44 ± 0.04
Liquid, -78, none	0.51 ± 0.02
Liquid, -78, DPPH	0.54 ± 0.03
Solid, -114 ^d	0.64 ± 0.02
Solid, est. -190 ^d	0.67 ± 0.02

^a Corrected for diastereomer purity and radioactive decay.

^b DPPH = diphenylpicrylhydrazyl. ^c The I₂-scavenged runs are not included in the average in the text because of the formation of large quantities of I¹²⁸ species which create a very high counter background during the passage of the Cl³⁸ peaks. ^d DPPH was present, but no information was obtained about the phase behavior of the solid binary mixtures.

When either of the 2,3-dichlorobutanes was irradiated in the gas phase (2 cm. pressure), the Cl³⁸ activity was reduced by a factor of 15-20 in the irradiated molecule from that observed in the liquid phase, and was zero within the limits of error in the diastereomer. The large increase in the radioactivity of the parent molecule between gas and liquid phases is consistent with previous observations.^{3,9} The chemical origin of the small fraction found as the radioactive parent molecule in the gas phase is uncertain, since γ -ray cancellation can very occasionally leave the original C-Cl bond unruptured.¹⁰

Prior to the experiments, three simple results seemed possible: (a) complete retention of configuration during substitution, as in recoil tritium substitution of T for H; (b) complete inversion, in analogy with the substitution of X⁻ into RX^{11,12}; and (c) complete racemization from the combination of Cl³⁸ with a racemized CH₃CHClCH₂ radical. None of these simple explanations can account by itself for the experimental

(9) J. E. Quinlan, Ph.D. Thesis, University of Wisconsin, 1958.

(10) Experiments by A. A. Gordus and C. Hsiung [*J. Chem. Phys.*, **36**, 955 (1962)] have shown that the original bonds survive the nuclear reaction and recoil in 0.1-0.5% of the activated molecules in the gas phase for Br and I radioactivities.

(11) E. D. Hughes, F. Juliusberger, S. Masterson, B. Topley, and J. Weiss, *J. Chem. Soc.*, 1525 (1935).

(12) C. A. Bunton, "Nucleophilic Substitution at a Saturated Carbon Atom," Elsevier Publishing Co., New York, N. Y., 1963.