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NAME OF AUTHOR *NOM DE L'AUTEUR* Jacky C. Godard

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NAME OF SUPERVISOR / *NOM DU DIRECTEUR DE THÈSE* Dr R.J. Crawford

DATED / *DATÉ* June 27 1975 SIGNED / *SIGNÉ* Godard

PERMANENT ADDRESS / *RÉSIDENCE FIXE* 14, rue Michelet
79 200 Parthenay
FRANCE

THE UNIVERSITY OF ALBERTA

THERMOLYSIS OF DEUTERIUM LABELLED 4-ETHYLIDENE-1-PYRAZOLINES

by

© JACKY C. GODARD

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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FALL, 1975

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Thermolysis of Deuterium Labelled 4-Ethylidene-1-Pyrazolines," submitted by Jacky C. Godard in partial fulfilment of the requirements for the degree of Master of Science.

Dr. R. J. Crawford - Supervisor

Dr. R. S. Brown

Dr. I. G. Dalla Lana - Chemical Engineering

Date June 26 1975

TO MY WIFE

ABSTRACT

The deuterium labelled pyrazolines, (E)- and (Z)-4-ethylidene-1-pyrazolines-3,3-$\underline{d}_2$ (I) and (II), have been synthesized and characterized. The thermolysis of I at 160° gave, in addition to deuterated ethylidene cyclopropane (III), 76% of 2-methylmethylenecyclopropane-3,3-$\underline{d}_2$ (IV) and 24% of 2-methyl-1-(dideuteriomethylene)cyclopropane (V). The thermolysis of II at 160° gave 10% of III, and 90% of a mixture consisting of 19% of IV and 81% of V. From the product ratios, it appears that the mechanism does not involve an orthogonal trimethylenemethane intermediate. It is suggested that the reaction goes through a transition state wherein the carbon-nitrogen bond syn to the methyl group is broken to a lesser extent than the other one, and from which the major product is formed via a concerted pathway.

ACKNOWLEDGEMENTS

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HISTORICAL

MECHANISMS FOR THE THERMOLYSIS OF 4-ALKYLIDENE-1-PYRAZOLINES

Introduction

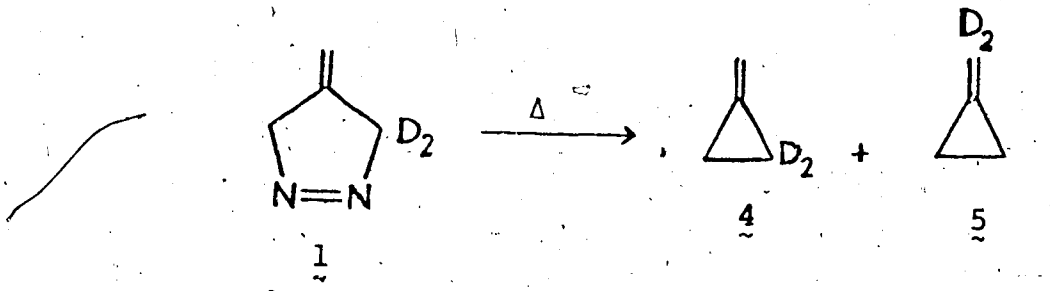
Trimethylenemethane (TMM), a diradical of composition $C(CH_2)_3$, has proved to be of considerable theoretical and mechanistic interest. The calculations of Dewar and Wasson (1) have shown that both triplet and singlet states are possible for TMM and that the triplet TMM with a planar geometry is the most stable structure. However, in a form where one terminal is orthogonal to the plane of the other two, the open shell singlet, which has two unpaired electrons of opposite spin, is not much less stable. It has been reported that orthogonal TMM intermediates are involved in the thermolytic rearrangement of various methylenecyclopropanes (2,3). Photolysis and thermolysis of 4-methylene-1-pyrozoline have also given rise to trimethylenemethane as reported by Dowd (4), Crawford (5) and Gajewski (6).

A. THERMOLYSIS OF 4-METHYLENE-1-PYRAZOLINE

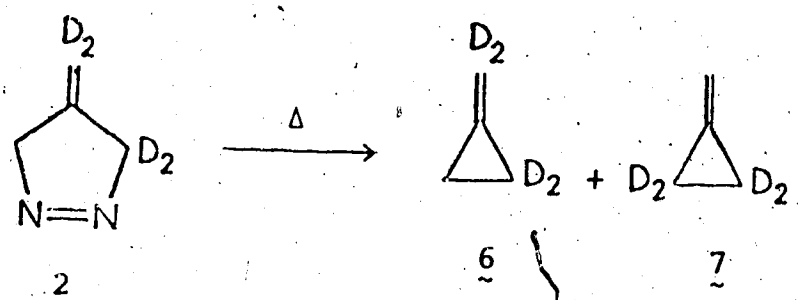
Crawford and Cameron (5) studied the thermolysis of 4-methylene-1-pyrazoline and suggested that a singlet trimethylenemethane (TMM) was produced.

Further investigation of the mechanism was achieved when 4-methylene-1-pyrazoline-3,3-d_2 (1), 3,3,6,6-d_4 (2) and

3,3,5,5,6,6-d_6 (3) were prepared and thermolyzed. The secondary deuterium kinetic isotope effects (k_H/k_D) corresponded to that expected for both carbon-nitrogen bonds undergoing simultaneous cleavage to form an intermediate. Pyrazoline 1 gave products 4 and 5, and 2 gave products 6 and 7 as in Table I.



1



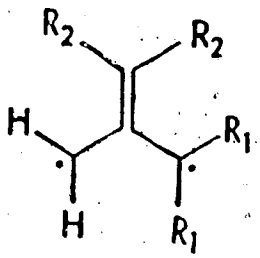
2

Table I

Thermolysis of deuterated 4-methylene-1-pyrazolines (1, 2)

Starting Material	Relative Yields, %	
	4	5
1	59.3	40.7
	6	7
2	73.8	26.2

If k'_H and k'_D are now defined as the rate constants for forming the exo-methylene group, the ratio k'_H/k'_D in the product determining step is 0.75 for the products of 1 and 0.74 for the products of 2 (7). These results suggest that there is an isotope effect in the product determining step and that the three methylene groups had either become equivalent in a planar TMM intermediate 8 or had become randomized in a set of orthogonal TMM intermediates 9.



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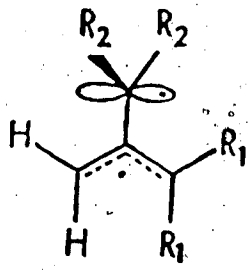


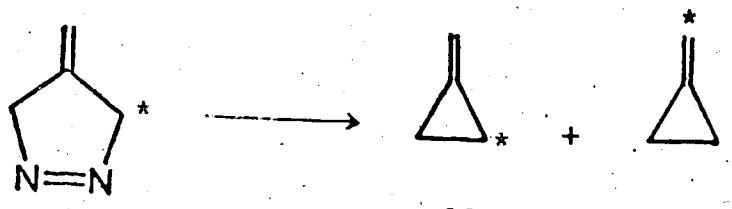
9

1 $R_1 = D$; $R_2 = H$

2 $R_1 = R_2 = D$

Triplet planar trimethylenemethane is known to dimerize to produce 1,4-dimethylenecyclohexane (8). Thus intermediate 8 was ruled out since no dimer was observed in any of the reactions, nor was there observed any addition product when it was attempted to trap the diradical with an olefin.

In a set of intermediates such as 9, the isotope effect was first thought to be a "ponderal effect": the deuterium, being of greater mass is slower to move out of the plane than is protium. By using carbon-13, any ponderal effect can be removed since the increase in mass is precisely on the axis of rotation. Tokunaga (7) obtained the following results upon studying the labelled pyrazoline 10.



10 11 12

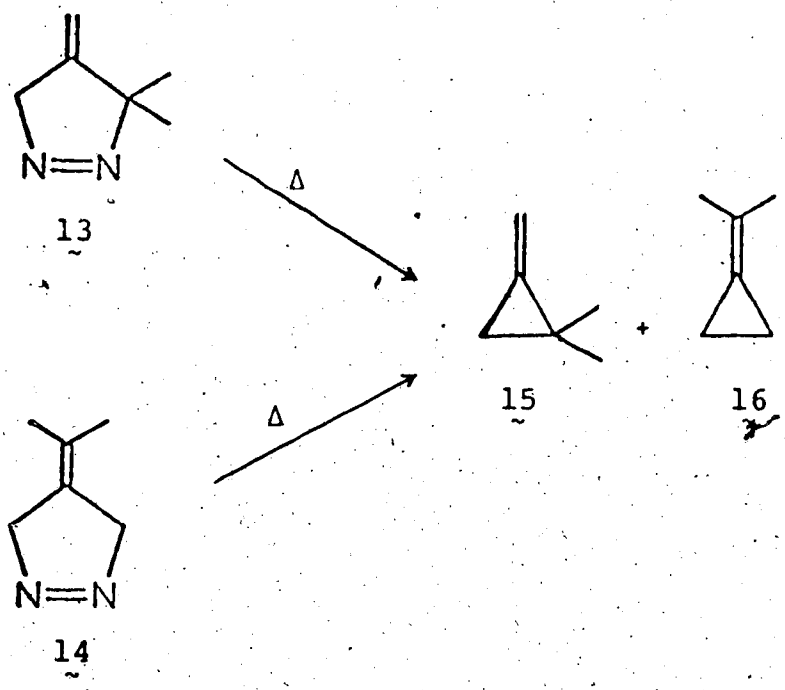
63.6% 36.4%

In this case, there cannot be a "ponderal effect", but still, the value found for the ratio 11 to 12 was 1.75, significantly different from the statistical value of 2.00.

The results for 1, 2 and 10 showed that the final position of a methylene group in methylenecyclopropane is dependent upon its original position in the pyrazoline. These results could not be accounted for with a mechanism producing intermediates like 9 alone.

B. THERMOLYSIS OF 3,3-DIMETHYL-4-METHYLENE-1-PYRAZOLINE AND 4-ISOPROPYLIDENE-1-PYRAZOLINE

Tokunaga (7) prepared the two isomeric dimethyl substituted 4-methylene-1-pyrazolines 13 and 14 and studied their thermolysis.



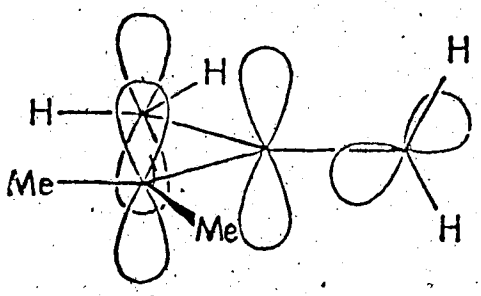
The product distribution obtained is indicated in Table II.

Table II

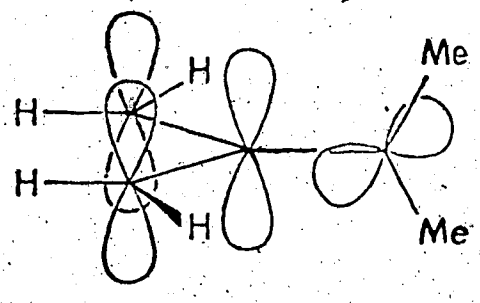
Thermolysis of dimethyl substituted 4-methylene-1-pyrazolines 13 and 14

Starting Material	Relative Yields %	
	15	16
13	82	18
14	63	37

From these results, a planar trimethylenemethane intermediate, common to 13 and 14 could be ruled out; instead, the singlet orthogonal intermediates 17 and 18 must be considered.

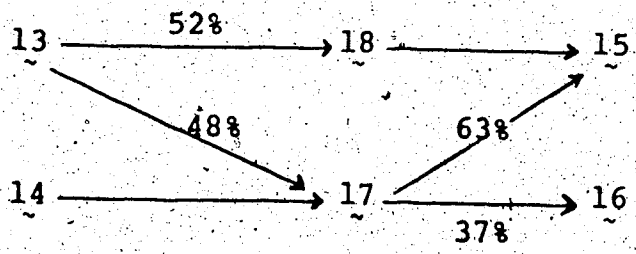


17



18

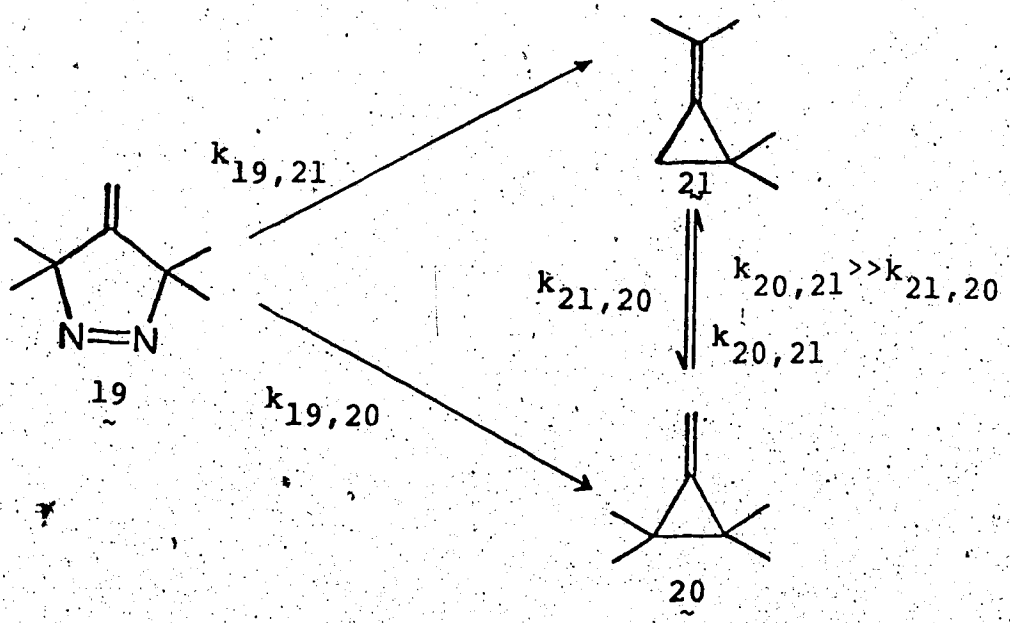
Crawford and Tokunaga (7) suggested, on the basis of the least motion principle, that thermolysis of 14 produces only 17 whereas thermolysis of 13 gives rise to 18 as well as 17. The product proportions could be then rationalized, assuming that the rotation of the isopropylidene group of 17 is favored 63:37 over that of the methylene group. Scheme I summarizes these results.



Scheme I

C. THERMOLYSIS OF 3,3,5,5-TETRAMETHYL-4-METHYLENE -1-PYRAZOLINE

Tokunaga (9) investigated the gas phase thermolysis of 3,3,5,5-tetramethyl-4-methylene-1-pyrazoline (19) which presented the advantage that the tautomerism which affected the study of the previous 4-methylene-1-pyrazolines, was no longer possible. Thermolysis of 19 gave rise to products 20 and 21 but 2,2,3,3-tetramethylmethylenecyclopropane (20) was not observed because of its rapid and nearly complete isomerization to give 2,2-dimethylisopropylidenecyclopropane (21) under the reaction conditions.



A kinetic study was carried out in order to determine all the rate constants and the initial ratio of 20:21.

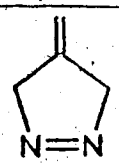
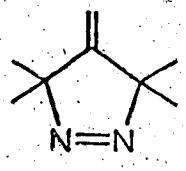
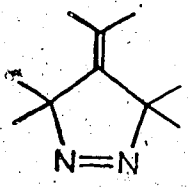
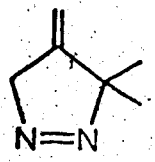
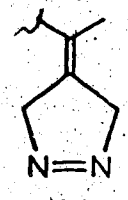
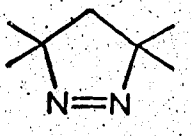
Comparison of the thermolysis rate of 19 with the thermolysis rates of some 4-alkylidene-1-pyrazolines, as listed in Table III proved to be interesting. It was found that the replacement of hydrogen by methyl slowed down the rate in contrast to what is normally expected. Also the rate of 19 was found to be one third the rate of 3,3,5,5-tetramethyl-1-pyrazoline (24) as if there was no acceleration from the allylic nature of the corresponding radical.

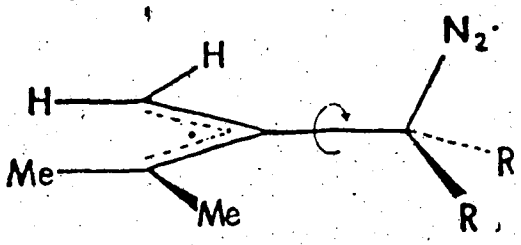
Crawford and Tokunaga (9) proposed that the bulky methyl groups had prevented any manifestation of the allylic resonance and suggested that the cleavage of the carbon-nitrogen bond(s) in 19 was occurring in the plane of the ring. Furthermore, results communicated by Professor Paul Engel showed that the thermolysis of 3,3,5,5-tetramethyl-4-isopropylidene-1-pyrazoline (23) was 32 times slower than the thermolysis of 19. This was an indication that even methyl groups placed on the exo-methylene group can, by their steric effect, influence the rate of the thermolysis of 4-alkylidene-1-pyrazolines. However, the activation parameters for 19 and 23 were sufficiently different from those observed for 22 to forbid any mechanistic comparison between these compounds.

Calculations gave 52:48 for the ratio of 20:21, from 19, a result different from the ratio of 15:16 (63:37) from 14. This difference could be rationalized by considering the allylic diazenyl species 25 as a possible intermediate.

Table III

The relative rates at 160.2° of some 4-alkylidene-1-pyrazolines with respect to 3,3,5,5-tetramethyl-4-methylene-1-pyrazoline

Compound	Relative Rate	Reference
 22	62.8	(7)
 19	1.0	(9)
 23	0.031	(10)
 13	21	(7)
 14	24	(7)
 24	3.0	(11)

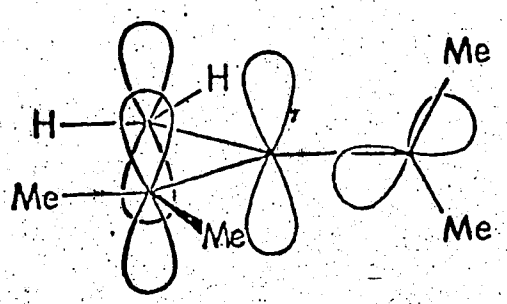


R = Me or H

25

Displacement of nitrogen by either of the allylic termini would then give rise to the products and this process may be controlled by the rotational conformations of 25 which differ when going from R = H to R = Me.

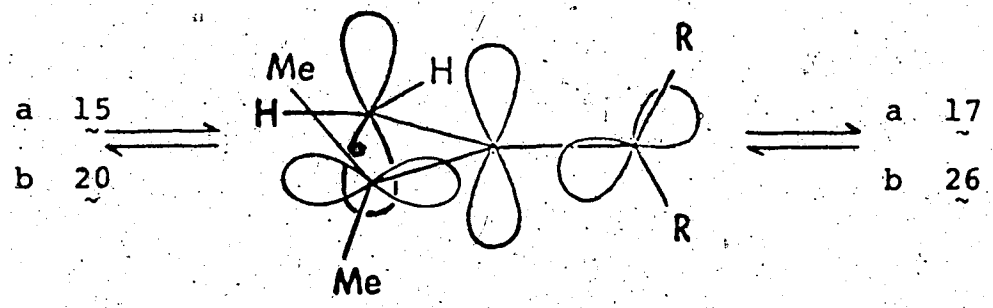
Crawford and Tokunaga also proposed 26 as a possible intermediate in the thermolysis of 19.



26

From this Chesick (2) type of intermediate, similar in structure to 17, an explanation had to be found for the fact that the rotational propensity of the isopropylidene group

with respect to the methylene group was greater (63:37) in 17 than it was in 26 (52:48). Crawford and Tokunaga suggested that, when going from intermediates 17 and 26 to products 15 and 20 respectively, the reaction had to go through a transition state TS, as shown in Scheme II.



TS a R = H

b R = Me

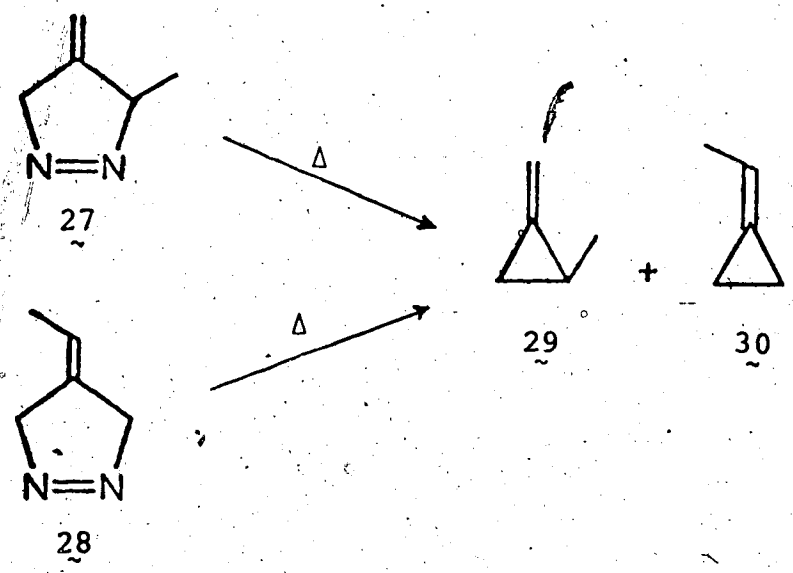
Scheme II

The lower rotational propensity of the isopropylidene group in 26 relative to that in 17 could then be rationalized in terms of steric factors more important in TSb than in TSa.

D. THERMOLYSIS OF 3-METHYL-4-METHYLENE-1-PYRAZOLINE AND 4-ETHYLIDENE-1-PYRAZOLINE

Schrijver (12) studied the thermolysis of the isomeric 3-methyl-4-methylene-1-pyrazoline (27) and 4-ethylidene-1-pyrazoline (28), two systems which were

supposed to exhibit different steric and electronic effects than the previously studied 4-methylene-1-pyrazolines.



The product distribution is given in Table IV.

Table IV

Product distribution of 29 and 30 produced from 27 and 28

Starting Material	Relative Yields %	
	29	30
27	80	20
28	90	10

From the results, a single planar TMM intermediate was ruled out since it would have given the same ratio of 29:30 regardless of the reactant used.

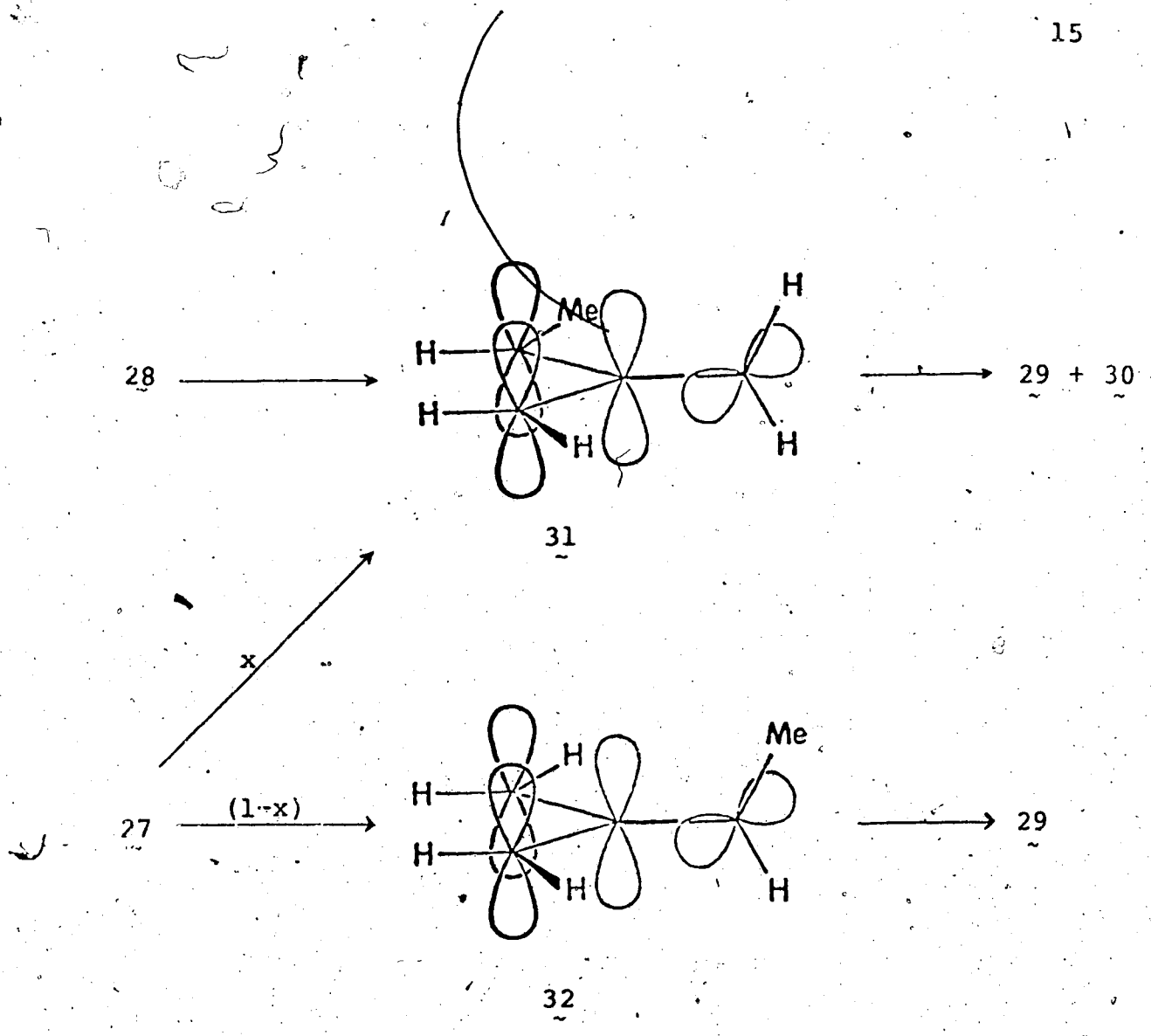
If a set of Chesick type intermediates 31 and 32 were to be proposed, 28 producing only 31 and 27 producing both 31 and 32 (Scheme III), then the relative amounts of 27 proceeding through 31 and 32 can be calculated. If x and (1-x) represent the mole fractions of 27 going through 31 and 32 respectively, then we can write the following equation by considering the ratio 30:29 from 27:

$$\frac{30}{29} = \frac{20}{80} = \frac{0.10\ x}{0.9\ x + 1-x}$$

or $\quad 0.40\ x = 0.9\ x + 1_T x$

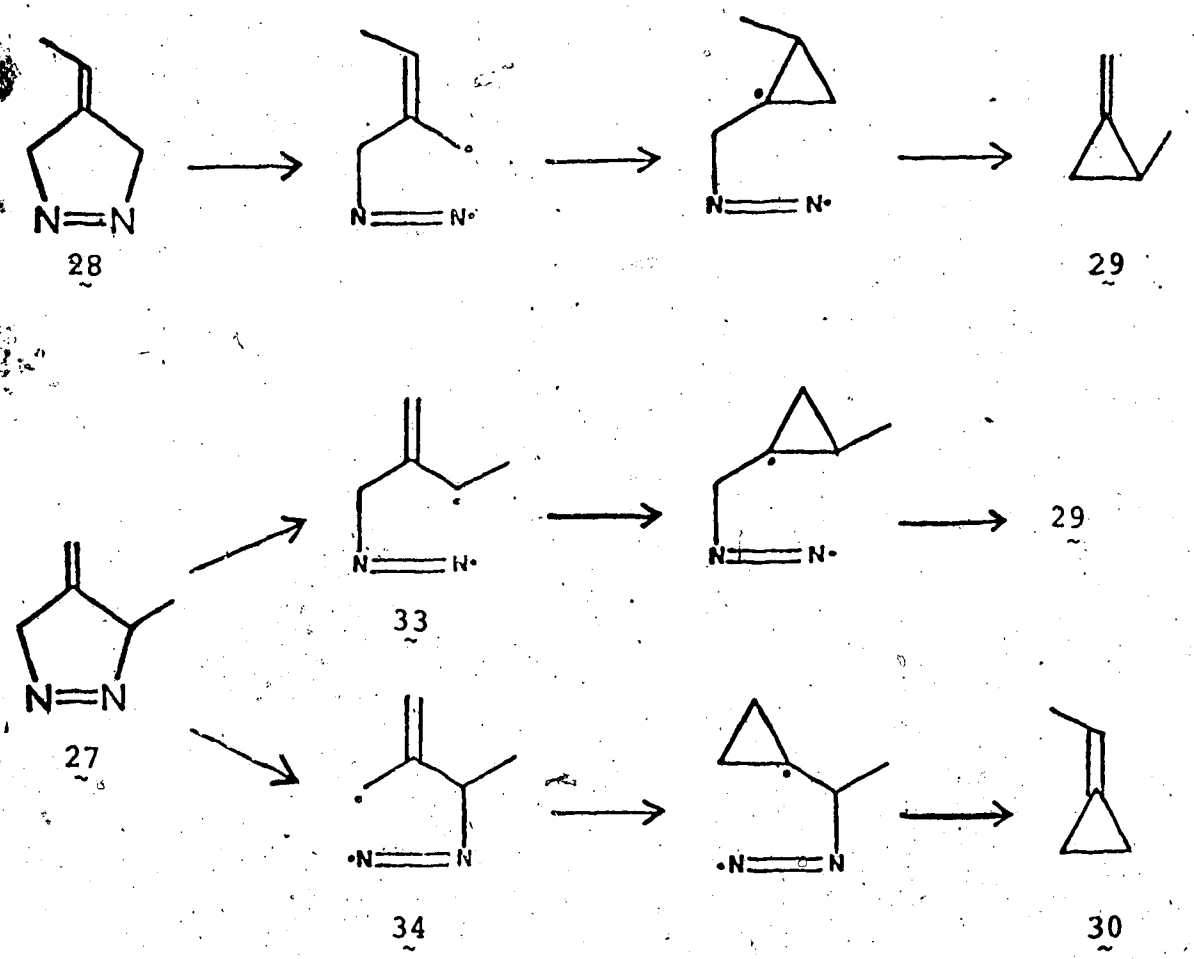
which gives $x = 2$

Such a ridiculous result at least suggested that, if the mechanism illustrated in Scheme III could account for the product distribution from 27 (a similar distribution was obtained from 13), it could not account for the product distribution from 28.



Scheme III

Schrijver (12) used a mechanism originally proposed by Cameron (13) and involving the breakage of only one carbon-nitrogen bond in the initial step and the formation of a cyclopropyl radical (Scheme IV).



Scheme IV

With this mechanism, the fact that the methylallyl radical 33 is easier to form than the allyl radical 34 could account for the excess of 29 with respect to 30 produced from 27. But this mechanism, although it closely fits the product proportions, does not rationalize the 10% of 30 produced from 28.

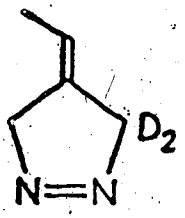
OBJECTIVE

Orthogonal trimethylenemethane intermediates (7,9,12) best interpret the product distributions obtained in the thermolysis of 3,3-dimethyl-4-methylene-1-pyrazoline (13), 4-isopropylidene-1-pyrazoline (14), 3,3,5,5-tetramethyl-4-methylene-1-pyrazoline (19) and 3-methyl-4-methylene-1-pryazoline (27).

However this kind of intermediate alone cannot account for the product distributions from 4-methylene-1- pryazoline (22) and its labelled derivatives 1 and 10 (7).

The case of 4-ethylidene-1-pyrazoline (28) is also peculiar (12) and the mechanism of the thermolysis of this system needs to be studied further.

This can be done by specific labelling of 28 — therefore we selected the pair of dideuterio-4-ethylidene-1-pyrazolines 35 and 36 — and examining the relative



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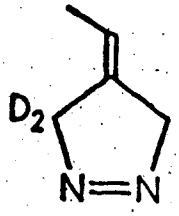
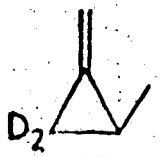
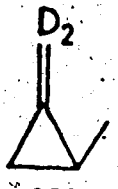


36

positions of the methylene groups in the 2-methylmethylene-cyclopropanes produced: 37a and 37b.



37a

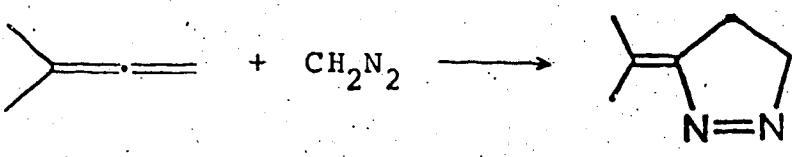


37b

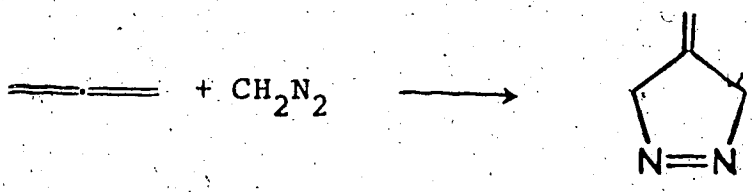
RESULTS

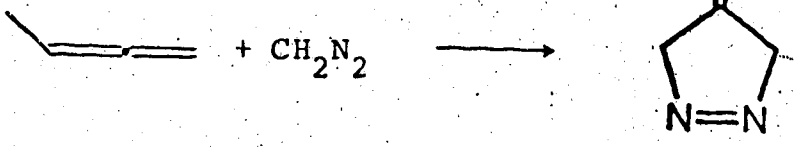
Introduction

Tokunaga (14) observed that the cycloaddition of diazomethane to 3-methyl-1,2-butadiene produced 3-isopropylidene-1-pyrazoline, whereas allene and methylallene give

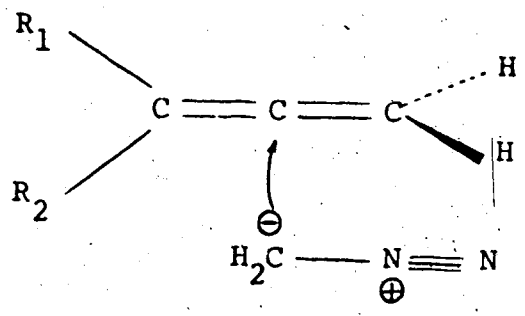


4-methylene-1-pyrazolines. Such a change in the direction of addition may be rationalized



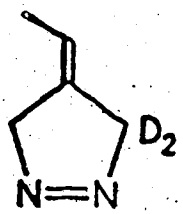


in terms of the methyl groups sterically blocking the nucleophilic attack of the diazomethane on the allenic

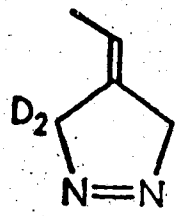


carbon when $R_1 = R_2 = CH_3$.

If this is correct, then by using diazomethane-$\underline{d}_2$, we may expect to produce (E)-4-ethylidene-1-pyrazoline-3,3-$\underline{d}_2$.



(E)



(Z)

This would allow a three point labelling of the groups and consequently give more information about the mechanism of the thermolysis of 4-alkylidene-1-pyrazolines.

(A) Synthesis

(E)-4-Ethylidene-1-pyrazoline-3,3-$\underline{d}_2$ (35) was prepared by the addition of dideuteriodiazomethane (38) to methylallene. The n.m.r. spectrum is shown in Figure 1.

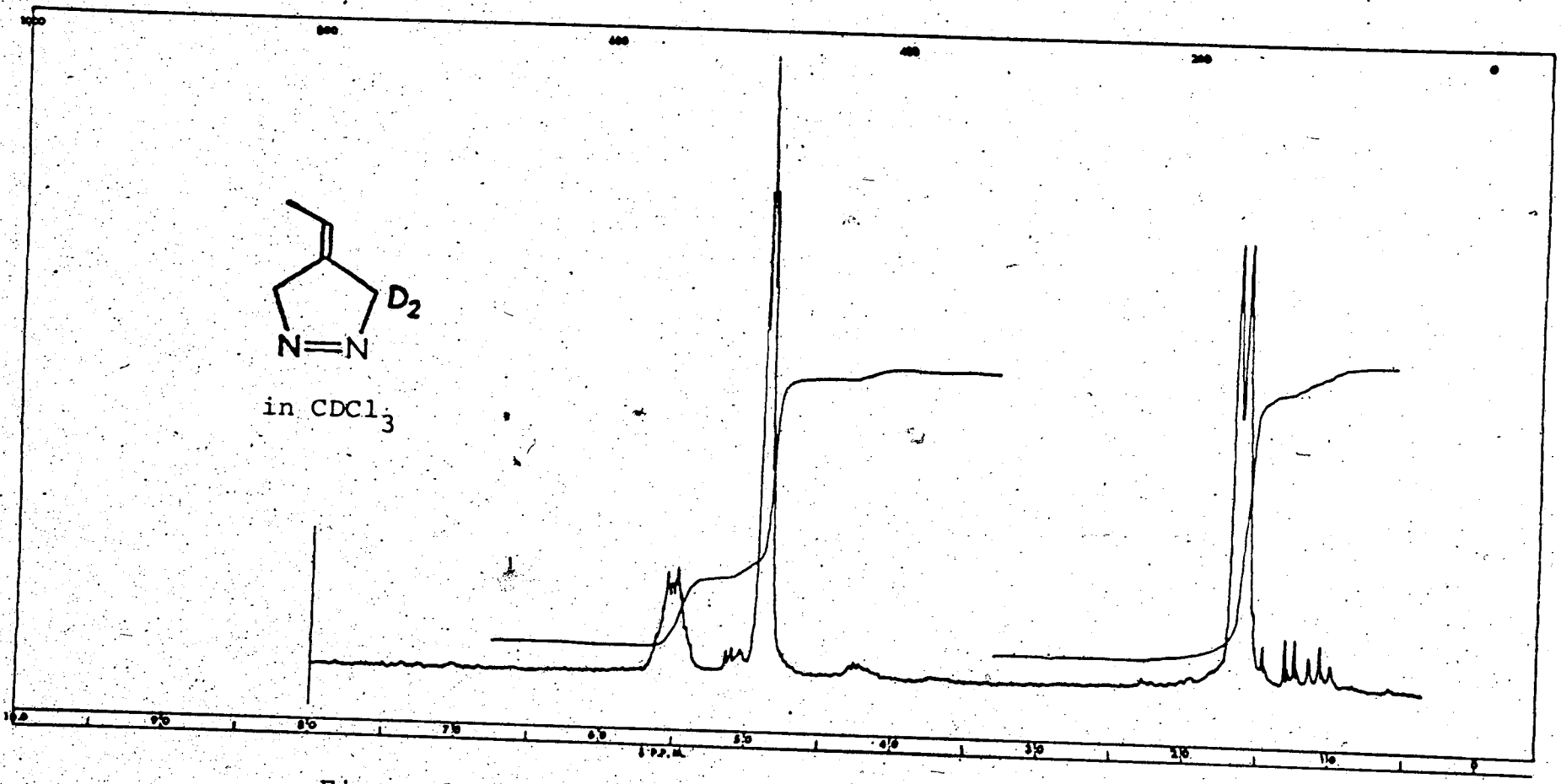
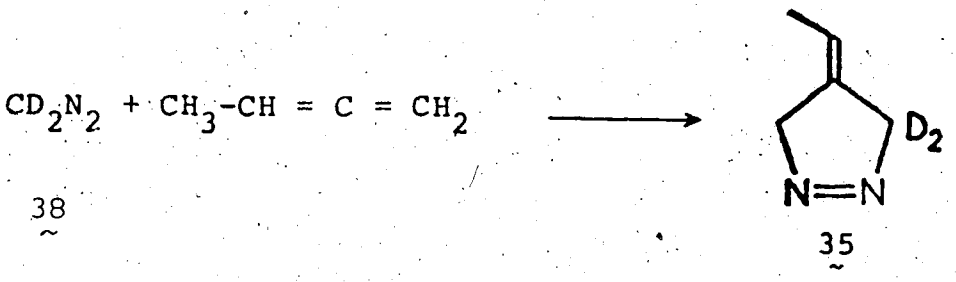


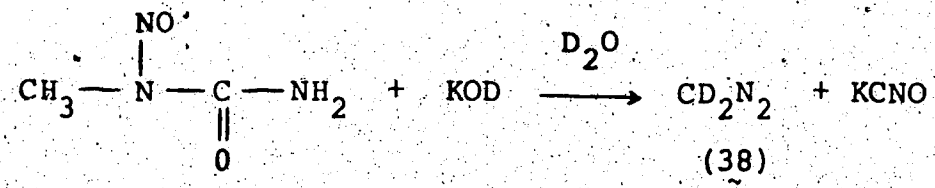
Figure 1: The 100 MHz n.m.r. spectrum of (E)-4-ethylidene-1-pyrazoline (35)



38 35

Methylallene was prepared from crotyl bromide, using the procedure described by Hurd and Meinert (15). Crotyl bromide, obtained from the reaction of crotyl alcohol with hydrobromic acid (16), was allowed to react with bromine at -5°C to give 1,2,3-tribromobutane. This tribromide was dehydrobrominated with NaOH to give a mixture of 1,2-dibromo-2-butene and 2,3-dibromo-1-butene. Treatment of this mixture of dibromobutenes with zinc in refluxing ethanol afforded methylallene.

Dideuteriodiazomethane (38) was generated from N-nitrosomethylurea by the action of potassium deuteroxide (17).



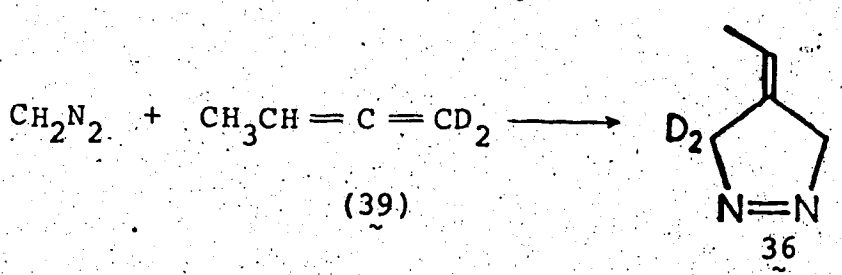
(38)

N-nitrosomethylurea was added cautiously to a solution of 1,2-dimethoxyethane and KOD - D_2O at 0°C. After stirring, the aqueous layer was frozen and the diazomethane solution

was decanted and dried over potassium hydroxide,

Reaction of diazomethane-$\underline{d}_2$ with methylallene in a pressure bottle at room temperature gave (E)-4-ethylidene-1-pyrazoline-3,3-$\underline{d}_2$ (35). This pyrazoline was not completely deuterated; the percentage of deuterium was found to be 74% on the basis of the integration of several n.m.r. spectra. Proof of the stereospecificity of this reaction will be given in the next section dealing with the n.m.r. of the compounds.

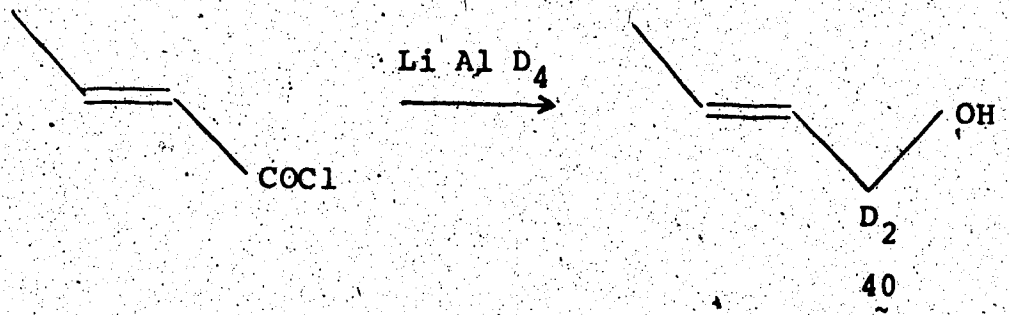
(Z)-4-Ethylidene-1-pyrazoline-3,3-$\underline{d}_2$ (36) was prepared from the addition of diazomethane to 1,2-butadiene-1,1-$\underline{d}_2$ (39). The n.m.r. spectrum is shown in Figure 2.



(39) 36

The deuterated methylallene 39 was obtained through a sequence of synthetic steps, identical to that described for the synthesis of unlabelled methylallene (15).

<u>trans</u>-2-Buten-1-ol-1,1-$\underline{d}_2$ (40) (crotyl alcohol) was prepared by the lithium aluminum deuteride reduction of trans-crotonyl chloride according to the procedure described by Schuetz (18).



40

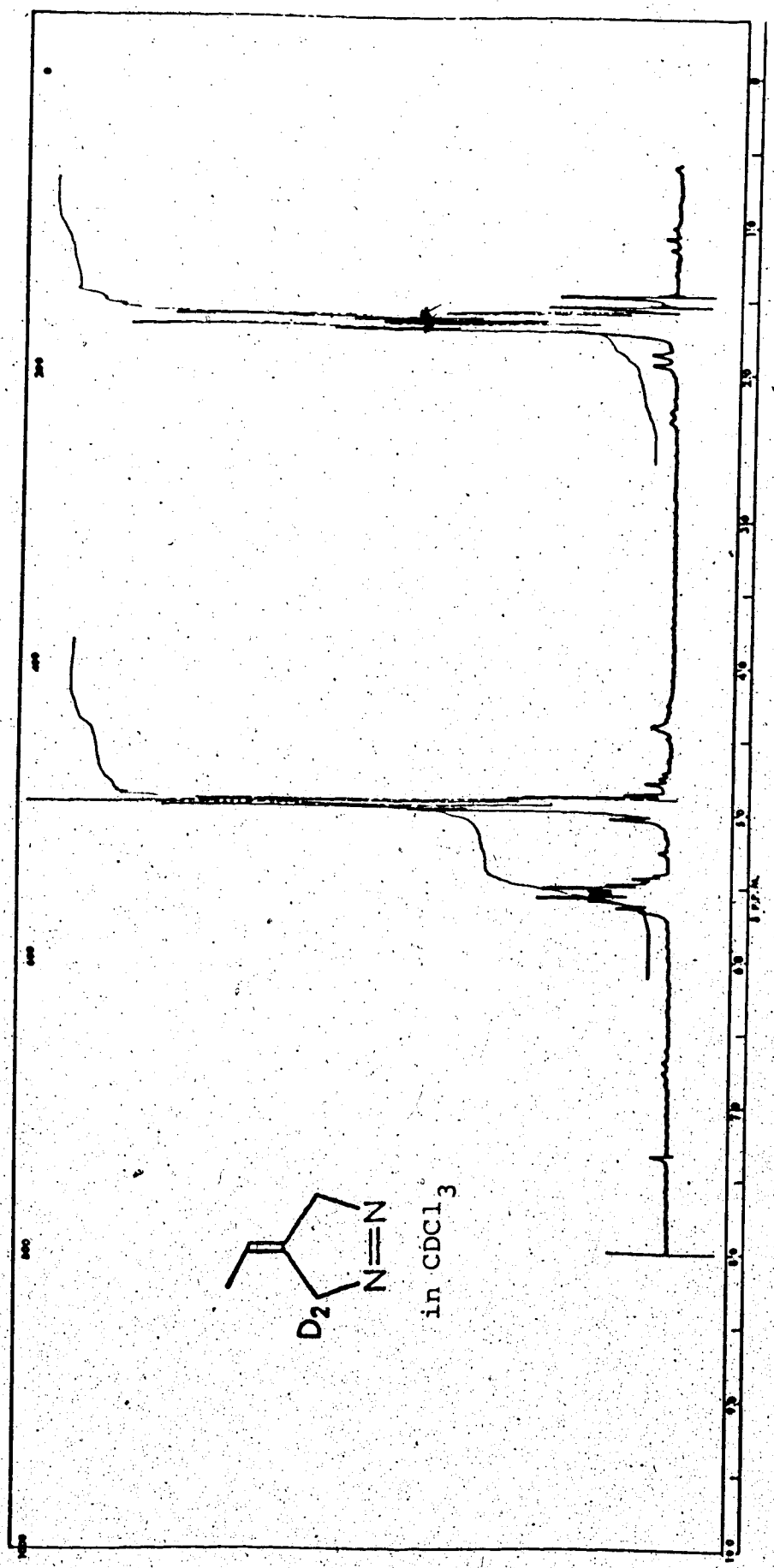
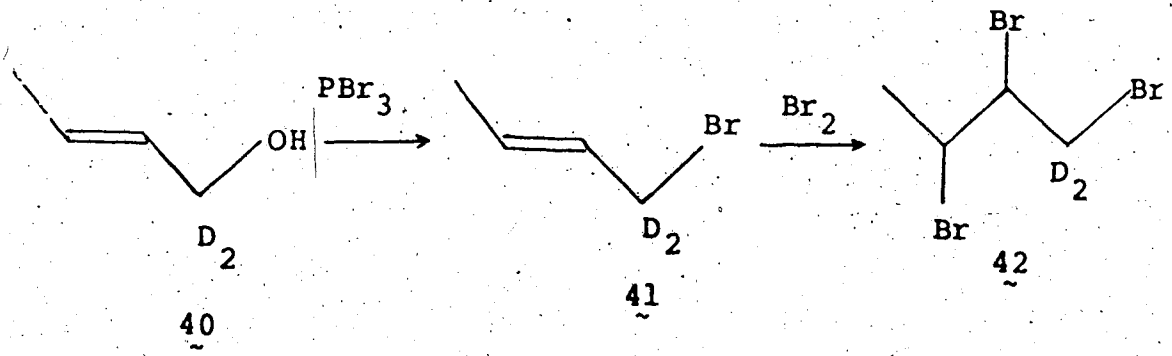


Figure 2: The 100 MHz n.m.r. spectrum of (Z)-4-ethylidene-1-pyrazoline (36)

The alcohol was converted into the corresponding bromide 41 with phosphorus tribromide (19). Addition of bromine to 41 gave 1,2,3-tribromobutane-1,1-d_2 (42).

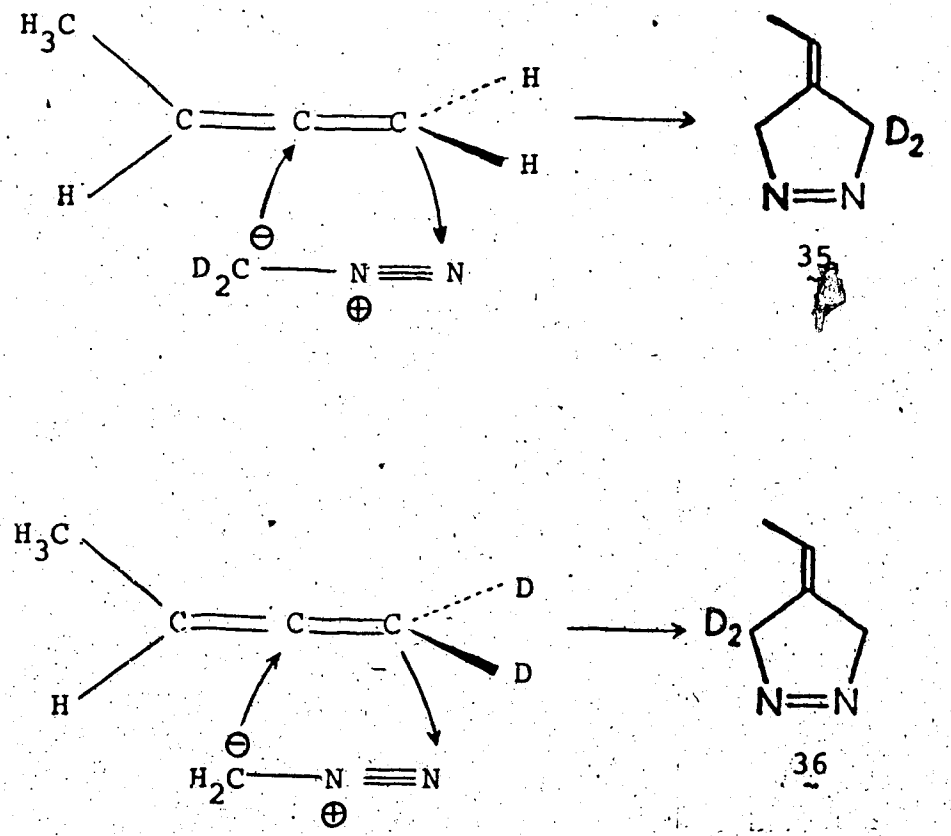


Dehydrobromination of 42 with sodium hydroxide gave a mixture of 1,2-dibromo-2-butene-1,1-d_2 (43) and 2,3-dibromo-1-butene-1,1-d_2 (44) where 43 predominated. Treatment of this mixture with zinc powder in refluxing ethanol afforded 1,2-butadiene-1,1-d_2.

The deuterium content of (Z)-4-ethylidene-1-pyrazoline-3,3-d_2 (36) could not be determined accurately. The n.m.r. spectrum indicated that there was at least 98% deuterium incorporation. Since the lithium aluminum deuteride used in the synthesis had a 99% isotopic purity and that no deuterium scrambling was observed throughout the synthesis, we assumed that the deuterium content was between 98 and 99%.

The specific synthesis of the two isomeric pyrazolines 35 and 36 via a cycloaddition reaction was made possible by a very interesting synthetic feature: the regiospecificity of

the addition of diazomethane to methylallene. Diazomethane only adds to methylallene on the side opposite to the methyl group, as shown in Scheme V.

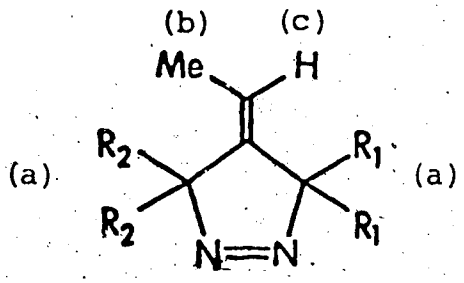


Scheme V

(B) Proof of Structures

Proof of structures 35 and 36 came from proton magnetic resonance and carbon-13 magnetic resonance.

Proton magnetic resonance data for 35 and 36 are given in Tables V and VI



35 $R_1 = D$, $R_2 = H$

36 $R_1 = H$, $R_2 = D$

Table V

Proton magnetic resonance data for 35

Proton	Chemical Shift (center) δ ppm	Type of Signal	Coupling Constants
a	4.91	doublet x quartet	Jab= 2.8cps
b	5.52	multiplet	Jbc= 6.85cps
c	1.63	multiplet	Jac= 1.95cps

Table VI

Proton Magnetic Resonance Data for 36

Proton	Chemical Shift (center) δ ppm	Type of Signal	Coupling Constants
a	4.95	quintet	Jab = Jac
b	5.55	quartet x triplet	= 2.25 cps
c	1.62	doublet x triplet	Jbc= 6.85cps

Comparison of the expanded signals of the methylene protons of both pyrazolines shows that the most intense line in the CH_2 signal of 35, at δ = 4.91 ppm is absent in the spectrum of 36 and reciprocally, the most intense line in the CH_2 signal of 36 [redacted]945 ppm is absent in the spectrum of 35. The c[redacted]stant Jab is smaller in 36 than in 35, and the co[redacted]nstant Jac is smaller in 35 than in 36. This is a pr[redacted] structures 35 and 36 since cis coupling constant[redacted]ound a double bond are known to be smaller than trans cou[redacted]ng constants.

[redacted]ther evidence for structures 35 and 36 came from the ^{13}C-[redacted]m.r. spectra of these compounds (Figures 3 and 4). The chemical shifts of the different carbon atoms and the relative intensities of the signals are given in Table VII.

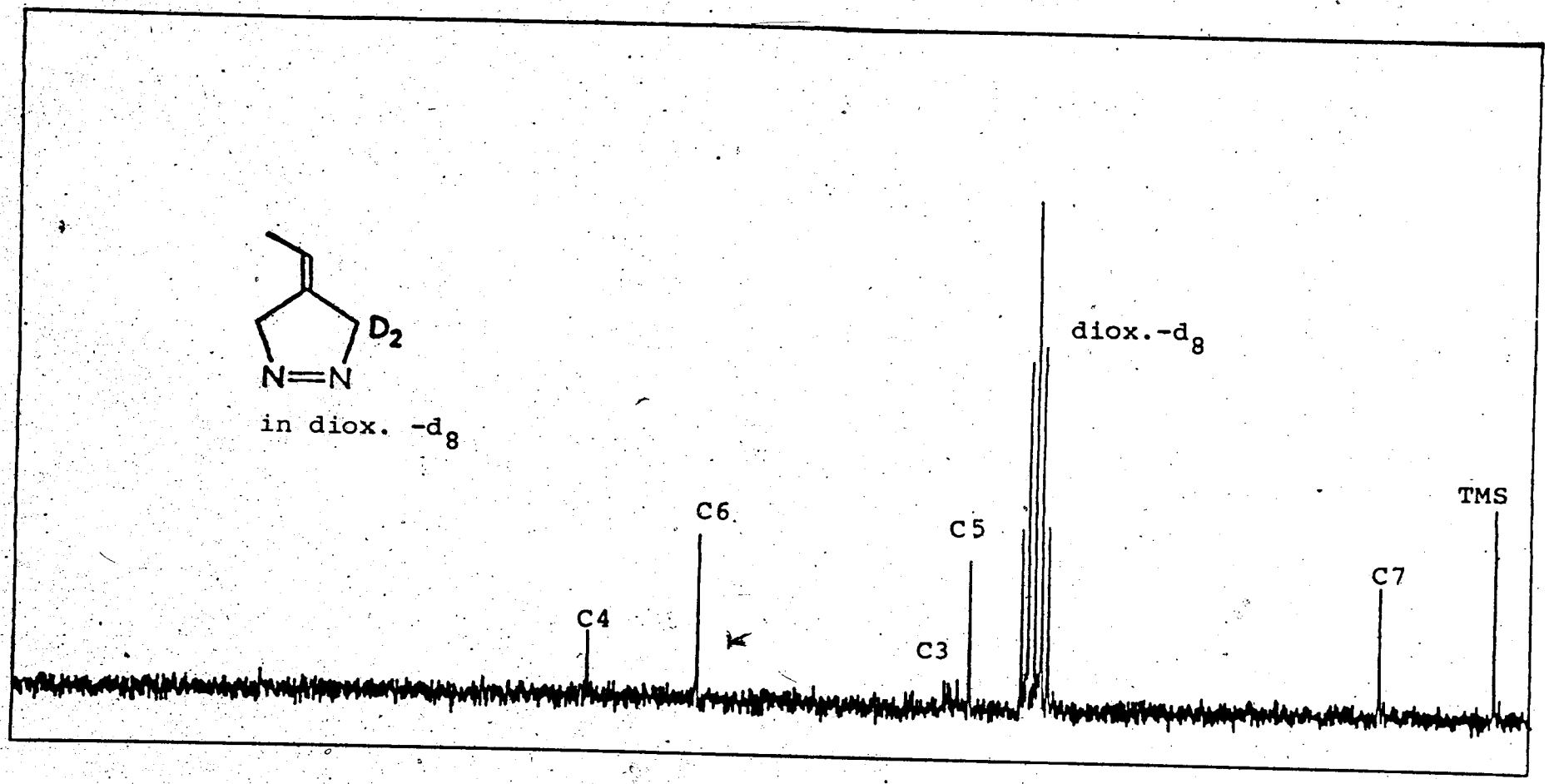


Figure 3: The 22.6 MHz ^{13}Cn.m.r. spectrum of (E)-4-ethylidene-1-pyrazoline (35)

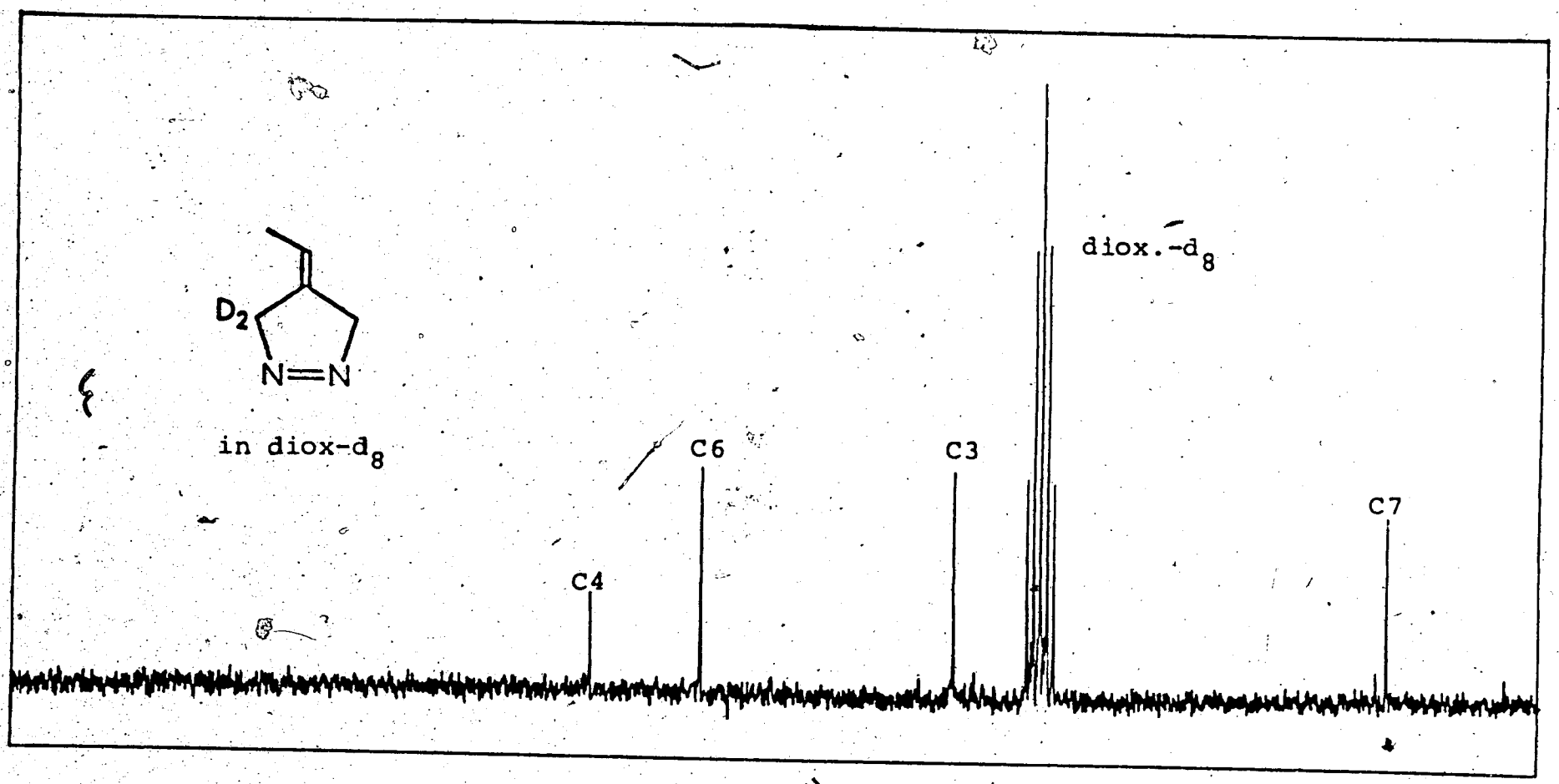


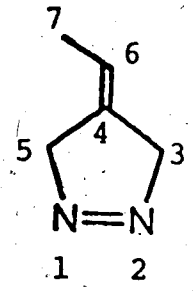
Figure 4: The 22.6 MHz ^{13}C n.m.r. spectrum of (Z)-4-ethylidene-1-pyrazoline (36)

Table VII

^{13}C n.m.r. data for 10, 28, 35 and 36*

Carbon n°	10	28	35	36
3	78.87	79.08 ; 1.06	78.76 ; -	79.09 ; 0.76
4	134.68	131.84 ; 0.48	131.74 ; 0.44	131.74 ; 0.36
5	78.87	76.06 ; 1.07	76.06 ; 0.87	- ; -
6	106.44	115.61 ; 1.00	115.66 ; 1.00	115.72 ; 1.00
7	-	16.34 ; 0.66	16.34 ; 0.62	16.35 ; 0.51

*The data for 10 were obtained prior to those for 28, 35 and 36, the spectra of which were run consecutively under strictly similar conditions. However, when the spectrum of 10 was run the spectrum of 28 was also run and the C3 signal appeared at 78.87 like in 10 whereas the C5 signal appeared at 75.91.



In Table VII, the first column represents the chemical shifts of the different carbon atoms in ppm with respect to TMS. The second column represents the relative intensities of the peaks; C6 was taken as a reference for intensities since it gives a strong signal, the intensity of which is not affected by deuterium substitution.

The assignment was made by comparing the ^{13}C n.m.r. spectra of the ^{13}C-labelled 4-methylene-1-pyrazoline (10) and 4-ethylidene-1-pyrazoline (28), and by using other chemical shift data (20).

Before the data of Table VII can be interpreted, it must be pointed out that deuterium substitution on a carbon atom:

- splits the signal of that carbon atom into $2I+1$ lines, with $I = 1$ for one deuterium and $I = 2$ for two deuterium atoms.

- increases the relaxation time T_1 of the carbon nucleus 36 times, therefore strongly decreasing the intensity of the signal (20).

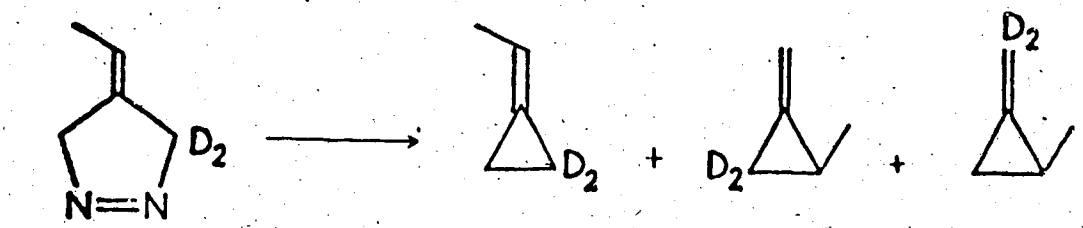
In the case of compound 35, the signal of C3 is considerably weakened as compared to the signal of the same carbon in 28. On an expansion of the spectrum, it appears as a set of four lines. The strongest line at 79.08 ppm is due to the d_o species, whereas the other three, forming a triplet, the center of which is shifted a little bit upfield at 78.76 ppm, belong to the d_1 species. The signal for the d_2 species which would appear as a quintet is not visible. On the other hand, for the same compound 35, the signal of C5 has undergone very little change with respect to the same signal in 28.

In the case of compound 36, the signal of C5 cannot be seen, due to a percentage of deuterium substitution close to 99%. However, the signal of C3 has undergone very little change with respect to the same signal in 28.

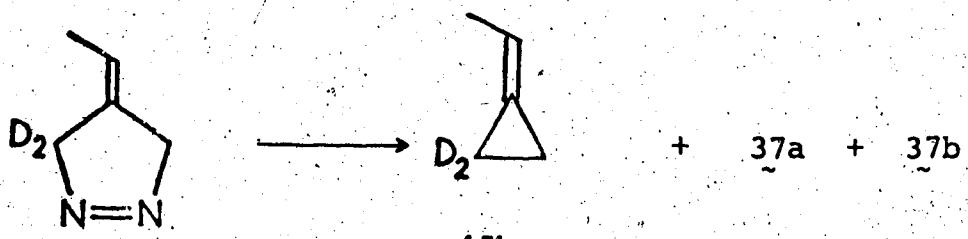
Thus, all these data agree with our assignment for structures 35 and 36.

(C) Thermolysis and Analysis of Products

Thermolyses of the pyrazolines 35 and 36 were carried out in breakseals at a pressure of approximately one atmosphere, at 160°, for one hour. The temperature of the oilbath was controlled to within ± 0.02°.



35 45a 37a 37b



36 45b 37a 37b

Under these conditions, it is known that the interconversion between 2-methylmethylenecyclopropane and ethylidenecyclopropane is negligible (2,12). Therefore, from each pyrazoline, the ratio of deuterated ethylidenecyclopropane and deuterated 2-methylmethylenecyclopropanes was determined by integration of the n.m.r. spectra of the reaction products. The n.m.r. spectra of the hydrocarbon reaction products from 35 and 36 are shown in Figures 5 and 6. The integrations from these spectra will be used in a later section to assign the proportions of ethylidenecyclopropane and 2-methylmethylenecyclopropane. In order to do this, we must first know the correct assignment of the protons in the

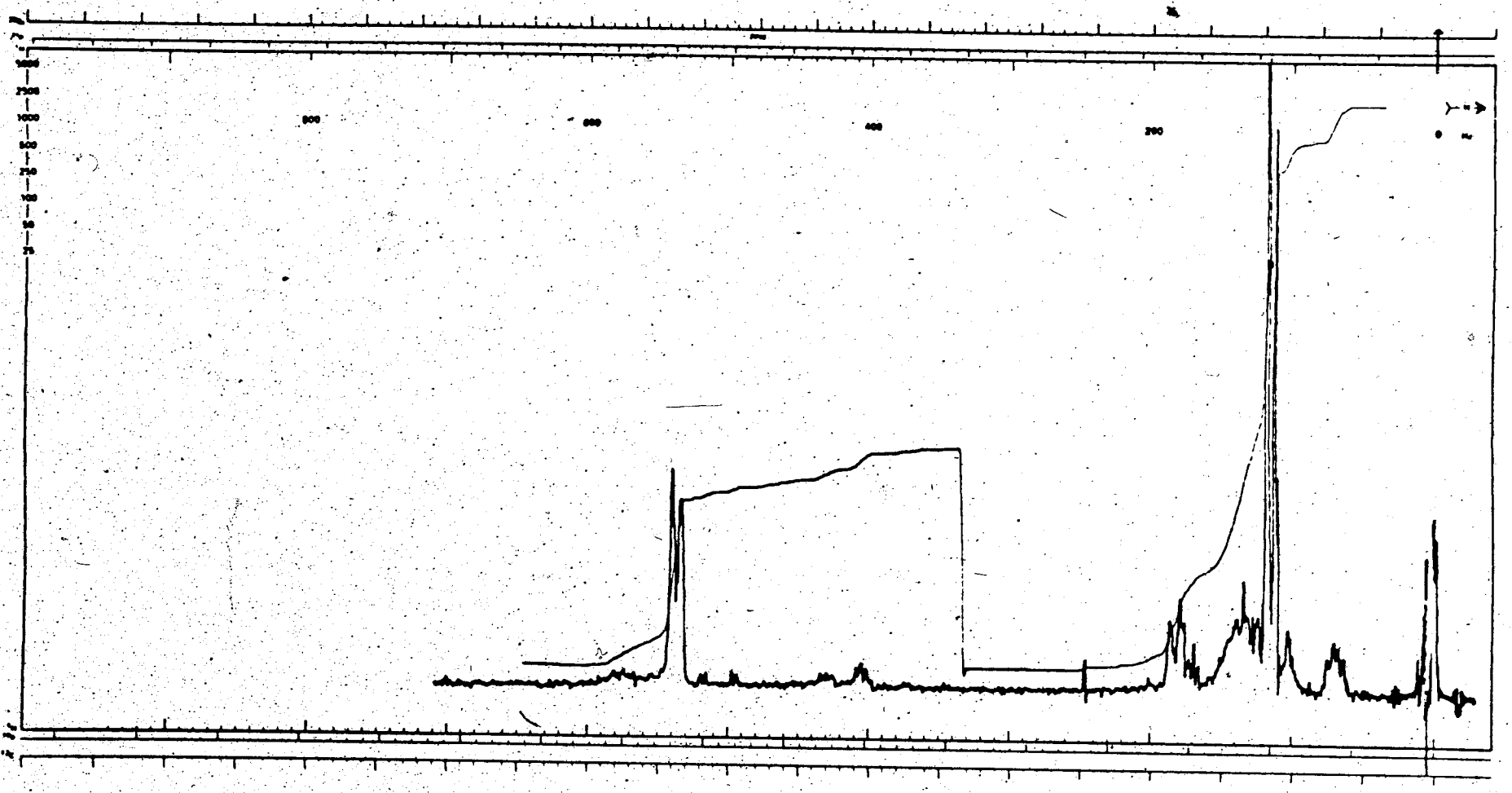


Figure 5: The 100 MHz n.m.r. spectrum of the hydrocarbon reaction products from 35

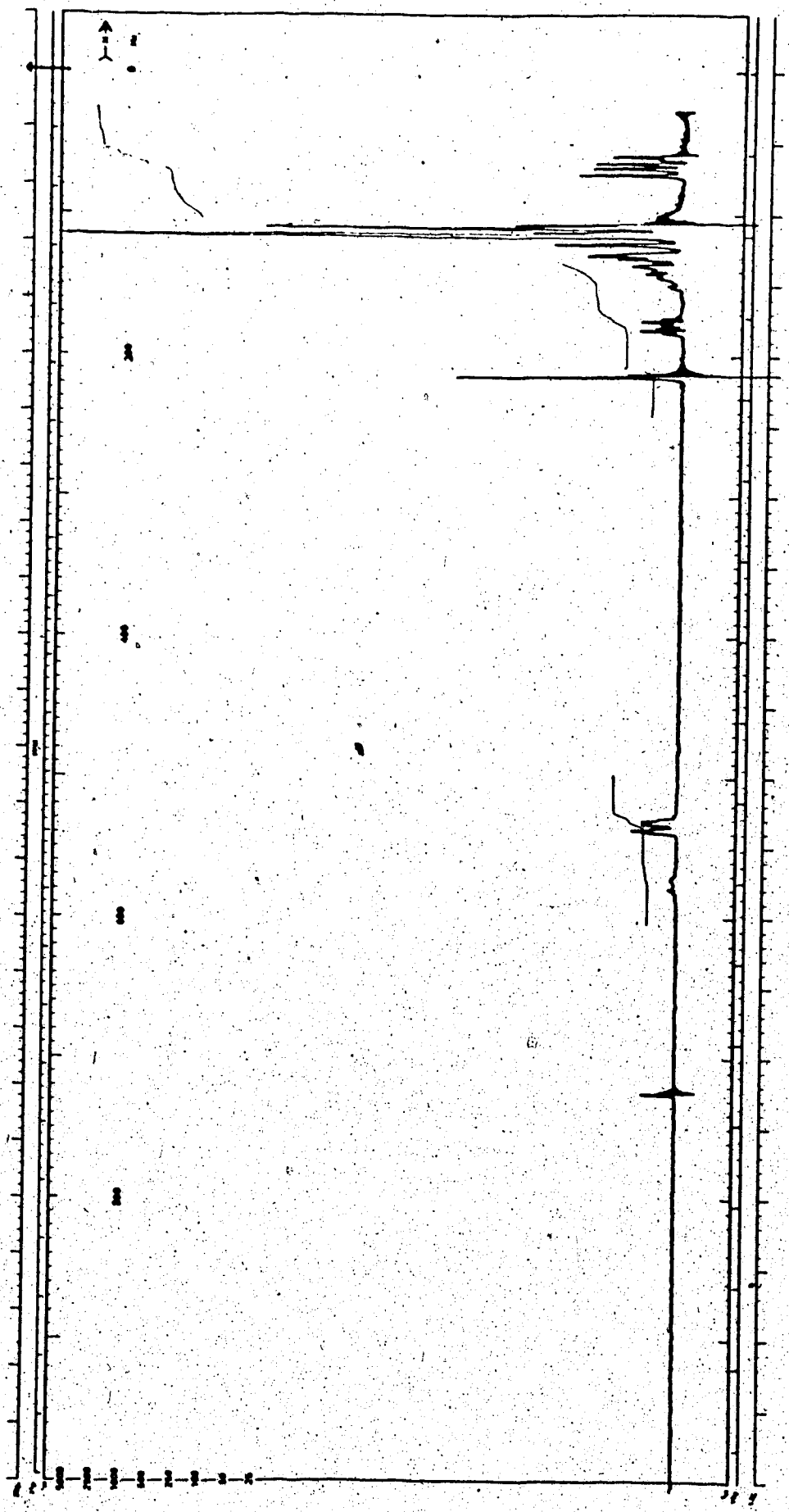
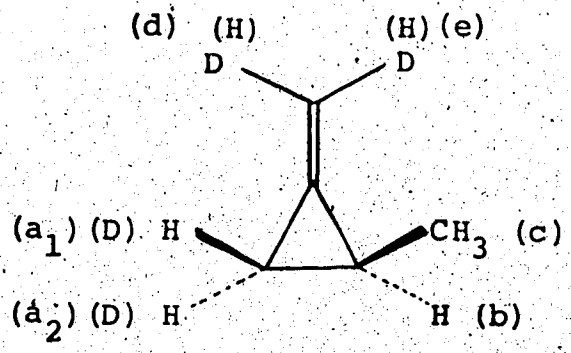


Figure 6: The 100 MHz n.m.r. spectrum of the hydrocarbon reaction products from 36

2-methylmethylenecyclopropane and the proportions of 37a and 37b.

Table VIII gives the assign ments for the n.m.r. spectra obtained from 37a and 37b (see Figures 7 and 8) which had been separated from ethylidenecyclopropane by preparative gas chromatography.



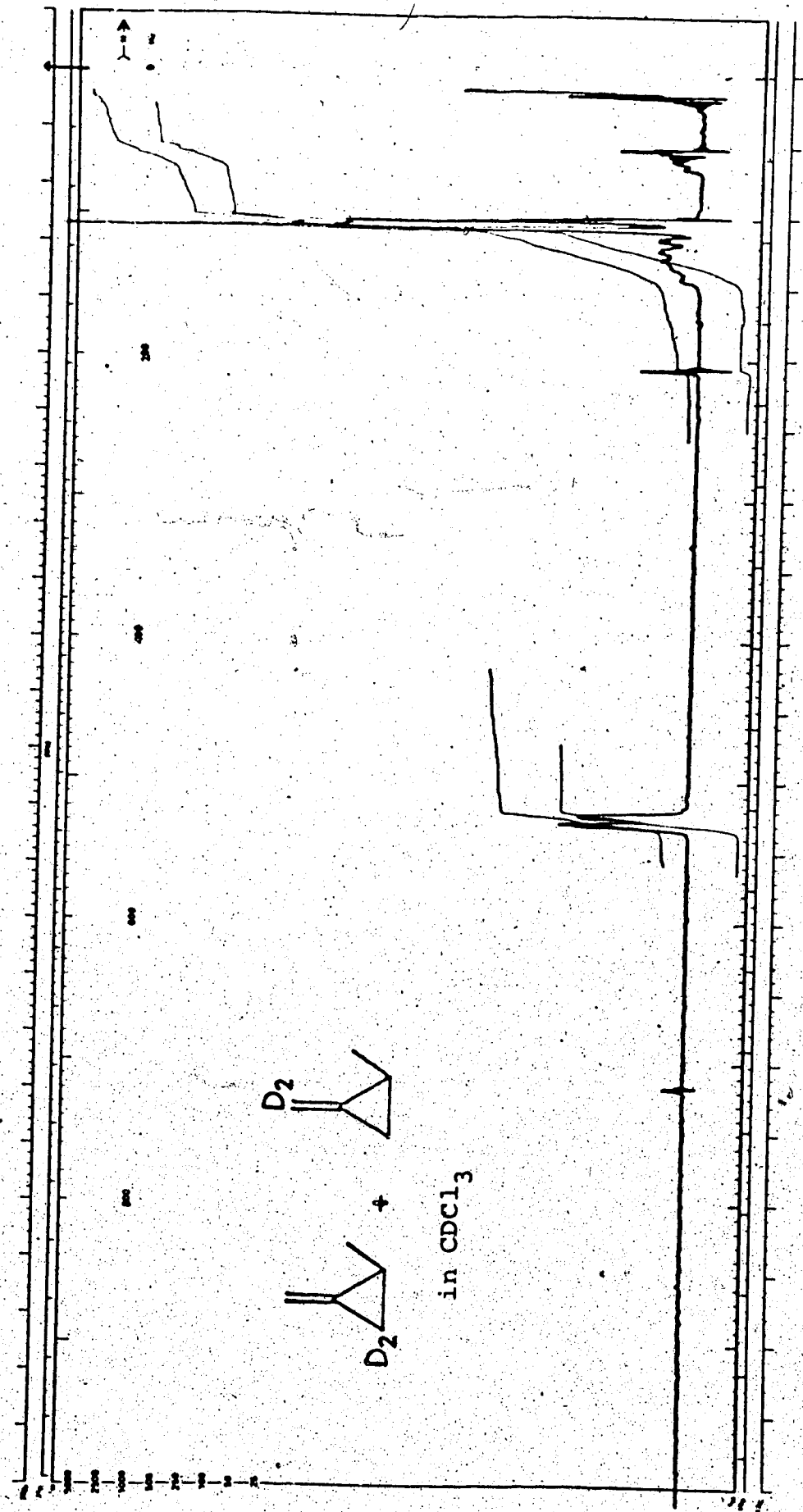


Figure 7: The 100 MHz n.m.r. spectrum of the mixture of 37a and 37b from 35.

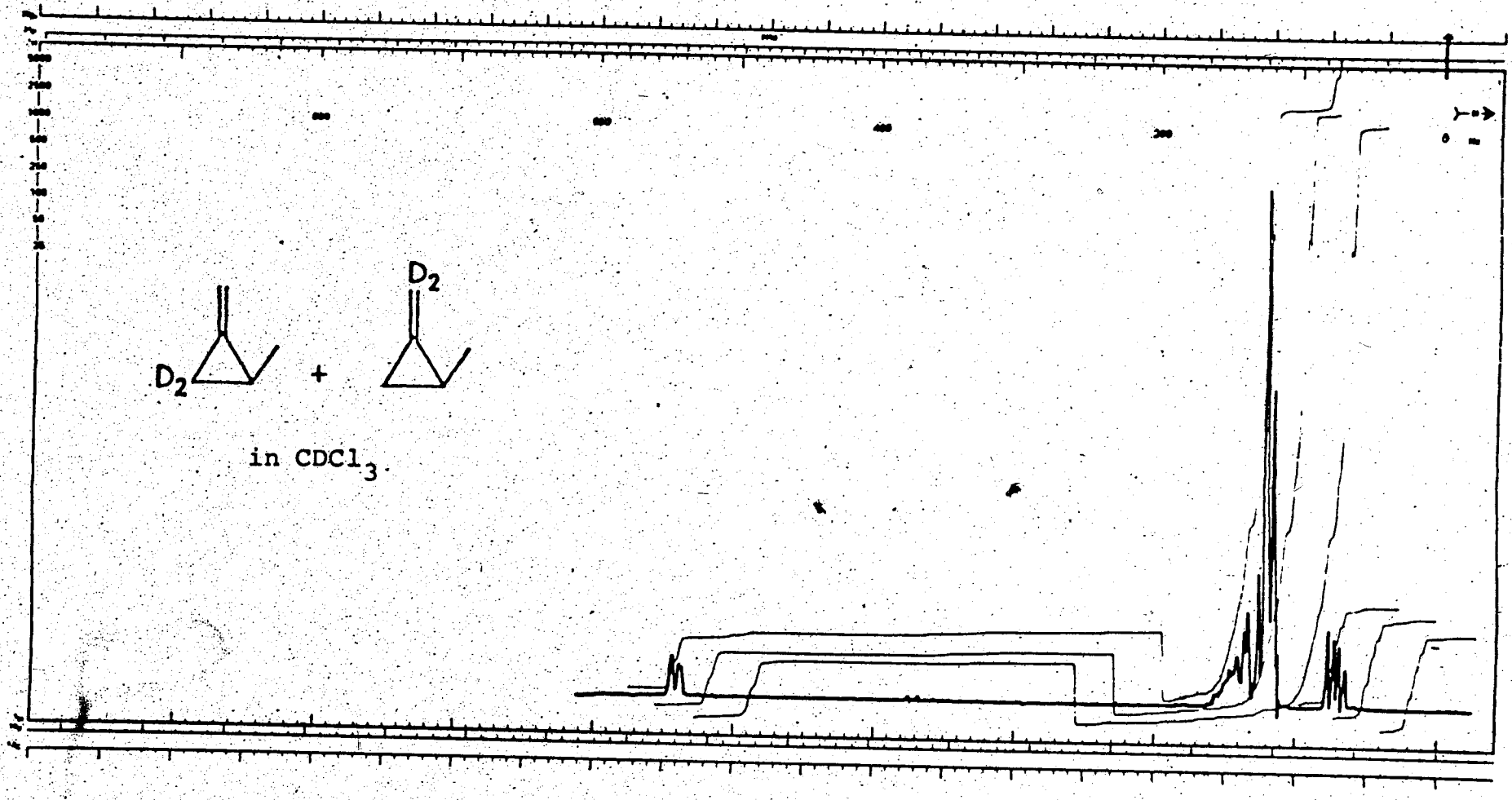


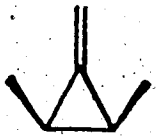
Figure 8: The 100 MHz n.m.r. spectrum of the mixture of 37a and 37b from 36

Table VIII

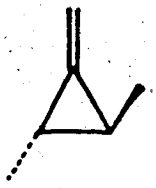
Nuclear magnetic resonance data for 37a and 37b

Proton	Chemical Shift δ ppm	Type of Signal	Coupling Constants
a_1	0.65	quartet	Ja_1b = 2.3 cps
a_2	1.1 - 1.55	multiplet	Ja_1a_2 = 4 cps
b	1.1 - 1.55	multiplet	Jbc= 2.6 cps
c	1.11	doublet	
d, e	5.36	doublet	

In order to make the correct assignment, the position of the proton appearing at very high field (δ = 0.65) on the spectrum was checked. In a decoupling experiment, the saturation of that proton left the methyl signal unchanged which proved that the high field proton was not H_b as proposed by Chesick (2). However, saturation in the δ = 1.46 region caused the decoupling of the methyl signal. The final choice between H_{a_1} and H_{a_2} for that high field proton was made with the aid of the chemical shift values reported by Gajewski (3) for cis - (46a) and trans-2,3-dimethylmethylenecyclopropane (46b).



46a



46b

In the case of 46a, the ring protons appear as a multiplet at δ = 1.45 ppm, whereas for 46b, they appear as a multiplet at δ = 1.0 ppm. In other words, the protons cis to the methyl groups are shifted upfield with respect to the protons trans to the methyl groups. Also by looking at the coupling constants affecting the signal of the high field proton, it appears that the largest coupling constant, with a value of 4cps, is a geminal coupling constant and that the second one, with a value of 2.3 cps is of the order of magnitude of a trans- rather than a cis- coupling constant in cyclopropanes (21).

Therefore, the proton at δ = 0.65 ppm can only be H_{a_1} whereas H_{a_2} and H_b give signals which stretch between δ = 1.1 and δ = 1.55 ppm and partly overlap with the methyl signal.

The nuclear magnetic resonance data for the (E)- and (Z)- ethylidenecyclopropanes-2,2,-d_2 (45a) and (45b) are given in Tables IXa and IXb and their spectra are shown in figures 9 and 10.

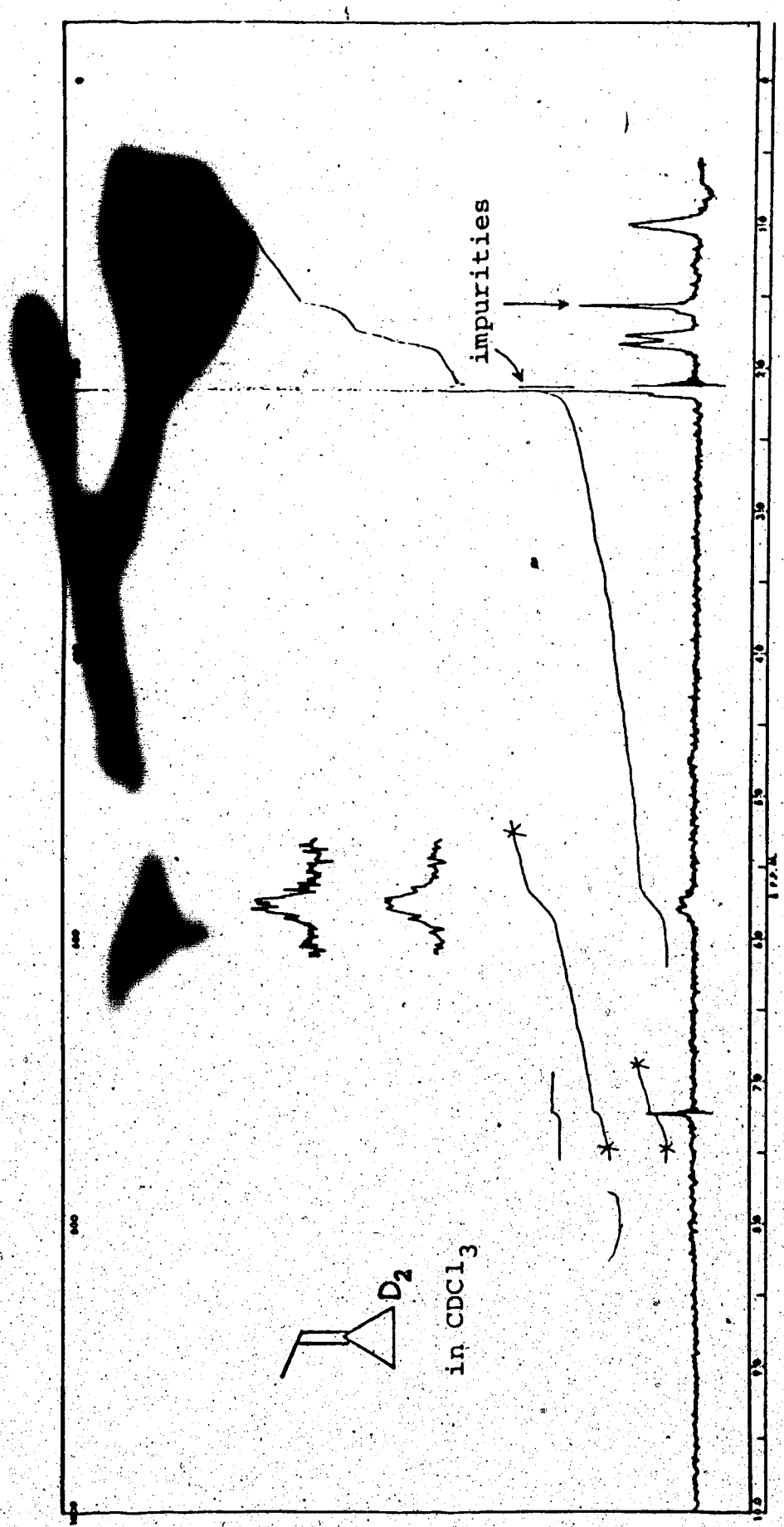


Figure 9: The 100 MHz n.m.r. spectrum of 45a produced from 35

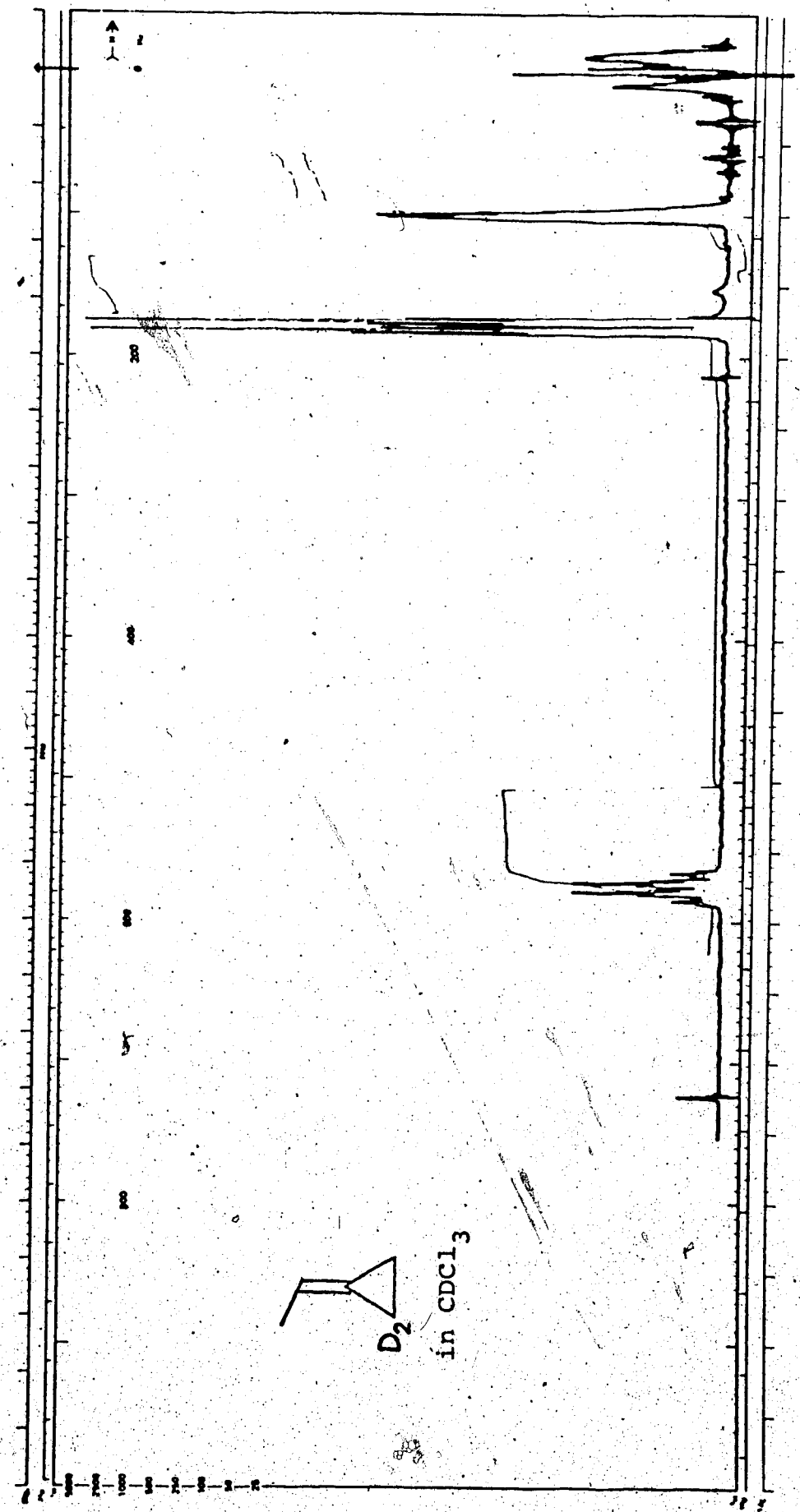


Figure 10: The 100 MHz n.m.r. spectrum of 45b produced from 36

Table IXa

Nuclear magnetic resonance data for 45a

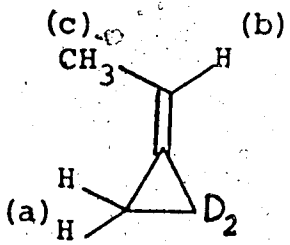
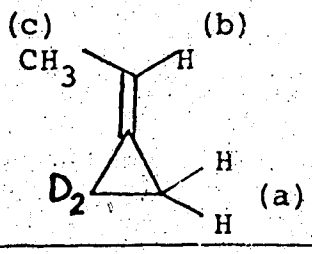
	Chemical Shift δ ppm	Type of Signal	Coupling Constants
a	1.02	multiplet	
b	5.77	multiplet	Jbc=6.4cps
c	1.78	doublet	

Table IXb

Nuclear magnetic resonance data for 45b

	Chemical Shift δ ppm	Type of Signal	Coupling Constants
a	1.00	multiplet	Jab=1.9cps
b	5.77	quartet x triplet	Jac=1.9cps
c	1.79	doublet x triplet	Jbc=6.4cps

Only one coupling constant could be determined from the spectrum of 45a and this made it difficult to prove structures 45a and 45b by n.m.r. exclusively. On the expanded spectra, the signals for the methyl and the ring methylene protons are different for 45a and 45b. For example, in the signal of the ring methylene protons, the distance between the two lines next to the central line is 3.7 cps in the case of 45a and 2.1 cps in the case of 45b. It is also interesting to compare these data with those reported by Gajewski (3) for anti- and syn- 2-methylethylidenecyclopropane. In the case of the anti- compound Gajewski describes the signal of the methyl group on the double bond as a doublet with fine structure which is what is also observed in 45a. In the case of the syn- compound, he describes the same signal as a doublet of quartets with coupling constants of 6.5 cps and 2 cps respectively which are very similar to Jbc and Jac observed in 45b. Thus, all these data support our assignment of structures 45a and 45b. Nevertheless we cannot exclude the possibility of up to 20% of 45a in 45b and vice-versa.

The proportions of 37a and 37b from the thermolysis of 35 and 36 were determined from the integration of the proton magnetic resonance spectra (Figures 7 and 8) and are given in Table Xa. In the case of the pyrazoline 35, the calculations were carried out on the basis of 74% deuterium incorporation, as determined by n.m.r.

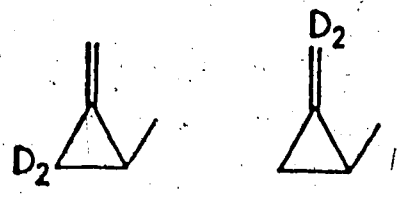
Table Xa

Proportions of 37a and 37b from the thermolysis of 35 and 36 as determined by ^{1}H.m.r.

Starting Material	Relative Yields %	
	37a	37b
35	74 ± 1	26 ± 1
36	22 ± 1	78 ± 1

The proportions of 37a and 37b from 35 and 36 were determined using the signal of the vinyl protons and the signal of the proton at highest field on the spectrum, which was identified as the proton cis to the methyl group on the cyclopropane ring. In the case of the products from the incompletely deuterated pryazoline 35, we found it convenient for the calculations, to consider a species 37a with 1.48 deuterium and 0.52 protium in the ring methylene and a species 37b with the same proportions of deuterium and protium in the exo-methylene group.* If n is the mole fraction of 37a present, and R represents the integration ratio of highest field versus vinyl protons, we can write the following equation:

*Actually in this case, five compounds are present: the d_o species, 37a-d_1 and -d_2 and 37b-d_1 and -d_2, but the problem is simplified by considering only two species.



1 - n n

$$R = \frac{0.26\ (1-n) + n}{2(1-n) + 0.52\ n} = \frac{0.26 + 0.74\ n}{2 - 1.48\ n}$$

$$\text{or} \quad n = \frac{2R - 0.26}{1.48\ R + 0.74}$$

From the spectrum, we find that $R = 0.28$

Thus $n = 0.26$

R is the ratio of two quantities measured on the n.m.r. spectrum. By taking ± 0.5 mm as the error on the measurements, we obtain for the error on R, the value $\Delta R = 0.01$.

$$R = 0.28 \pm 0.01$$

and $n = 0.26 \pm 0.01$

In the case of the products from 36, the following equation may be derived:

$$R = \frac{n}{2(1-n)} \qquad \text{or} \qquad n = \frac{2R}{2R+1}$$

This time, $R = 1.79$ and $n = 0.78$

The same error calculation gives $\Delta R = 0.07$

Thus $R = 1.79 \pm 0.07$

and $n = 0.78 \pm 0.01$

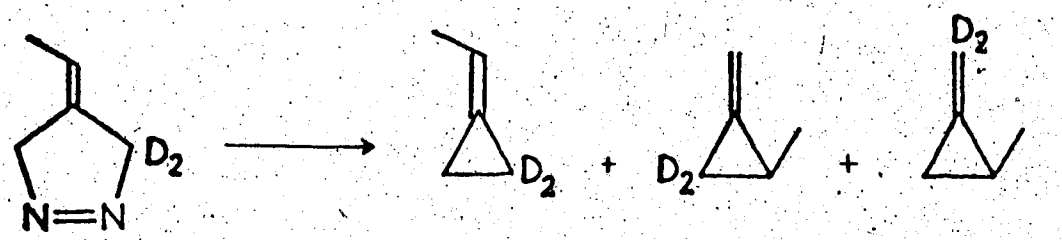
The knowledge of the proportions of 37a and 37b from the thermolysis of 35 and 36 now allows us to determine the whole product distribution from these thermolyses by integration of the n.m.r. spectra of the reaction products (see Figures 5 and 6). The results are given in Table Xb.

Table Xb

Product distribution from the thermolysis of 35 and 36

Starting Material	Relative Yields %	
	45a	37a + 37b
35	11 ± 1	89 ± 1
	45b	
36	10 ± 1	90 ± 1

In order to determine the ratio of (E)- ethylidene-cyclopropane-2,2-d_2 (45a) versus the mixture of 37a and 37b from pyrazoline 35, the following calculation was carried out:



35 x 0.74(1-x) 0.26(1-x)

For 45a, the ring methylene protons were chosen and for 37a and 37b, the high field proton, cis to the methyl group was chosen.

If R represents the ratio of the intensities of these protons, we can write the following equations:

$$R = \frac{2.52\ x}{0.26 \times 0.74\ (1-x) + 0.26\ (1-x)} = \frac{2.52\ x}{0.45\ (1-x)}$$

$$\text{or}\quad x = \frac{0.45\ R}{0.45\ R + 2.52}$$

The n.m.r. spectrum gives R = 0.70

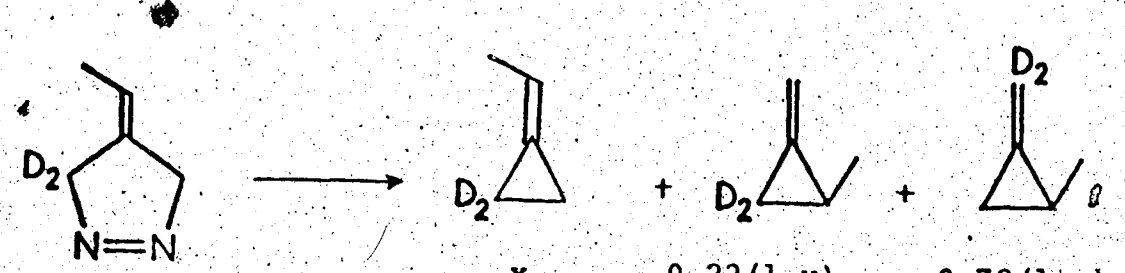
Thus x = 0.11

R is the ratio of two quantities measured on the n.m.r. spectrum. By taking ± 1 mm as the error on the measurements we obtain for the error on R, the value $\Delta R = 0.1$.

$$R = 0.7 \pm 0.1$$

and $$x = 0.11 \pm 0.01$$

In the case of the products from pyrazoline 36, the ratio of (Z) -ethylidenecyclopropane-2,2-d_2 (45b) versus the mixture of 37a and 37b was determined in a similar manner.



36

This time, for 45b, the methyl protons were chosen, and for 37a + 37b, the high field proton, cis to the methyl group was chosen.

If R represents the ratio of the intensities of these protons, we have

$$R = \frac{3x}{0.78\ (1-x)} \quad \text{or} \quad x = \frac{0.78R}{0.78\ R+3}$$

The n.m.r. spectrum gives $R = 0.44$

Thus $x = 0.10$

The same error calculation as for the products of 35 gives $\Delta R = 0.06$

Thus $R = 0.44 \pm 0.06$

and $x = 0.10 \pm 0.01$

Although a gas chromatographic analysis would have given more accurate results, the ratio of ethylidenecyclopropane and 2-methylmethylenecyclopropane as determined by n.m.r. is in excellent agreement with that reported by Schrijver (12).

In order to get more reliable quantitative results for the ratio 37a : 37b from each pyrazoline, the samples of the mixtures of 37a and 37b were subjected to a deuterium nuclear magnetic resonance (^2H n.m.r.) analysis at 13.815 MHz. The spectra are shown in Figures 11 and 12.

The advantages of this technique are that the spectrum only shows three very distinct signals: one for the exo-methylene deuterium and one for each of the ring methylene

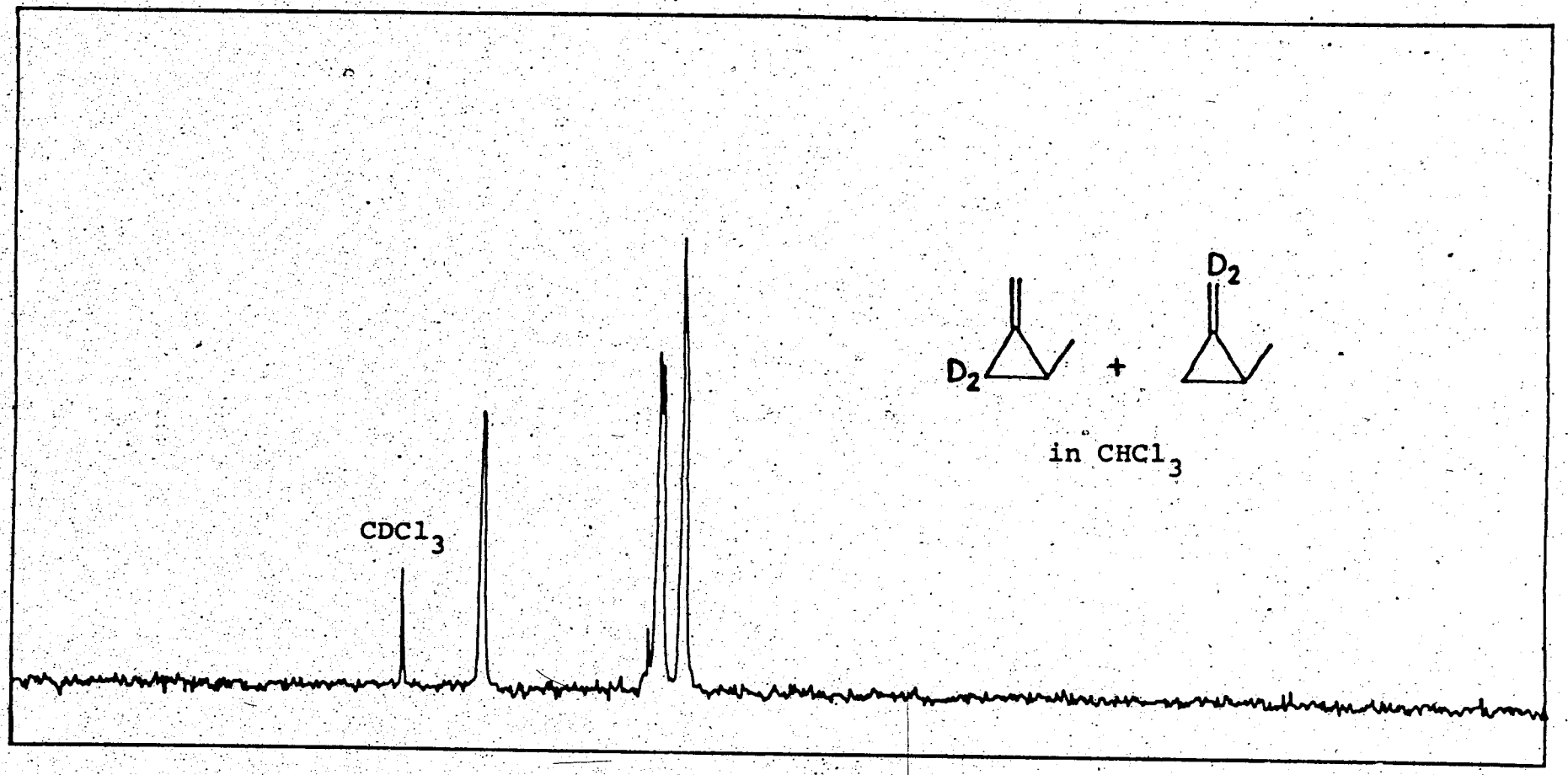


Figure 11: The 13.8 MHz ^{2}Hn.m.r. spectrum of the mixture of 37a and 37b from 35

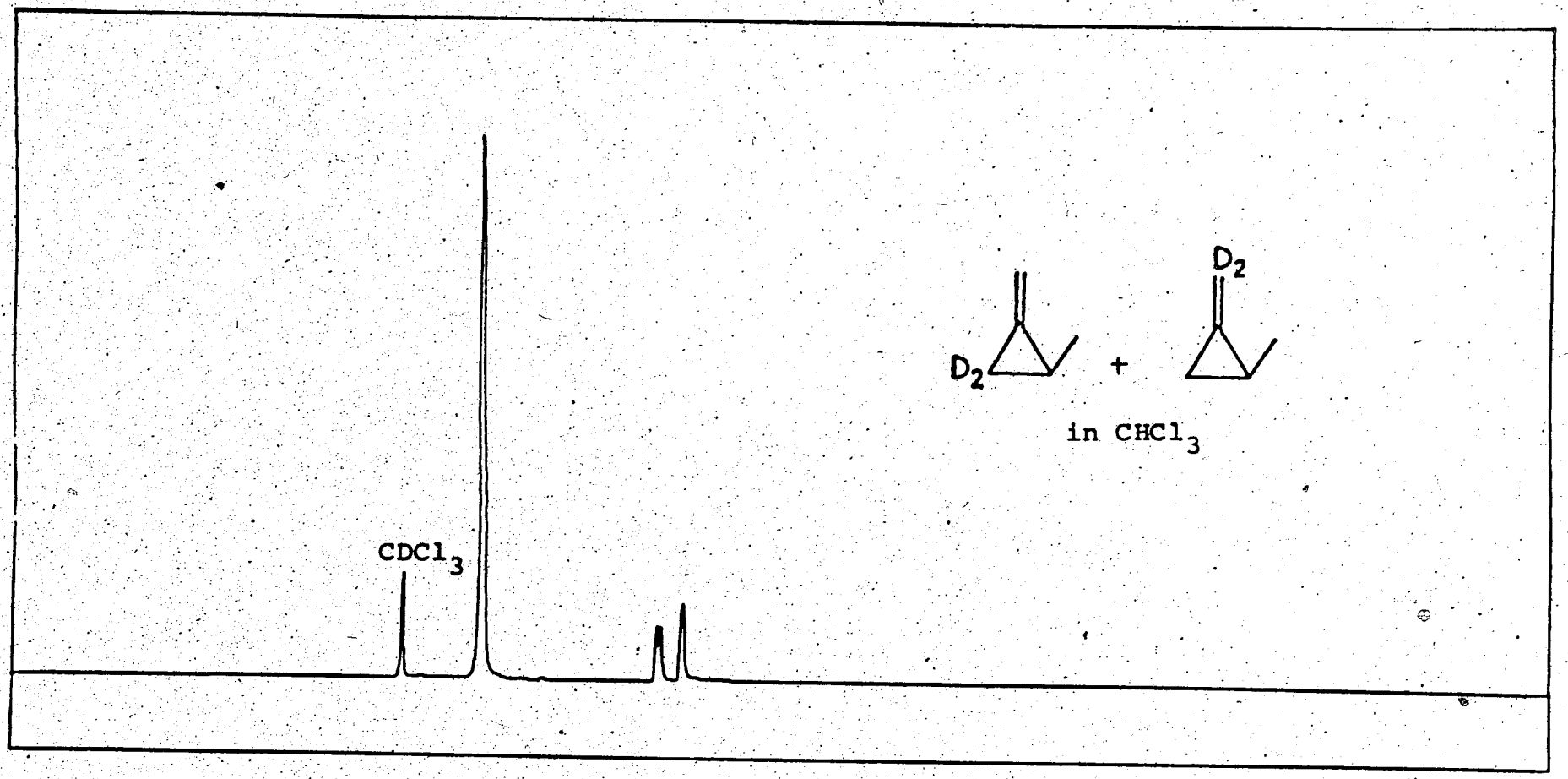


Figure 12: The 13.8 MHz ^{2}H n.m.r. spectrum of the mixture of 37a and 37b from 36

deuterium atoms, and that no correction is required for the percentage of deuterium incorporation since it is a direct determination unlike the indirect proton resonance method. From the technical point of view, when the Fourier transform n.m.r. experiment was carried out, pulses of relatively small flip angles were applied. This was done in order to let the deuterium nuclei relax completely between two pulses. Pulses with flip angles of about 45° and then about 10° were applied and it was found that the angle did not affect the intensity of the signals and that reproduceable values for the intensities were obtained within ± 1%. Computer programmed integration gave the exact values of the ratio 37a:37b from 35 and 36. The results are given in Table XI.

Table XI

Proportions of 37a and 37b from the thermolysis of 35 and 36, as determined by ^2H n.m.r.

Starting Material	Relative Yields %	
	37a	37b
35	76 ± 1	24 ± 1
36	19 ± 1	81 ± 1

(D) Control Experiments

Gilbert (22) observed that 2,2-diphenyl-1-(dideuteriomethylene)cyclopropane (47a) isomerizes at 80° to give 2,2-diphenylmethylenecyclopropane-3,3-d_2 (47b). Therefore, we found it necessary to examine the possibility of interconversion between 2-methylmethylenecyclopropane-3,3-d_2 (37a) and 2-methyl-1-(dideuteriomethylene)cyclopropane (37b). A sample of the reaction mixture from the thermolysis of 36, in chloroform, was carefully degassed and heated at 160.2°. An n.m.r. spectrum was taken before the test, after one hour and after four hours. The results are given in Table XII.

The ratio 37b:37a remains constant within experimental error. This result could have been expected since the phenyl substitution makes the activation parameters for the interconverion of 47a and 47b ($\Delta H^{\ddagger}$ = 22.1 kcal/mol) quite different from those calculated from Chesick's data (2) on the

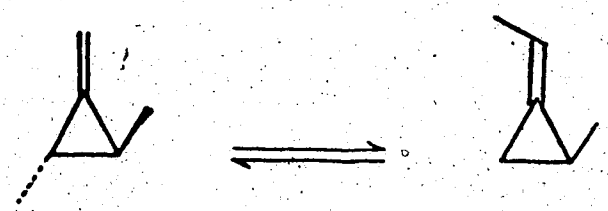
Table XII

Influence of time on the product distribution of the thermolysis of 36, at 160.2°

Time	37a : 37b	37a + 37b : 45b
0	81.7 : 18.3	90.1 : 9.9
1 hour	81.1 : 18.9	89.9 : 10.1
4 hours	80.9 : 19.1	88.5 : 11.5

equilibration of 2-methylmethylenecyclopropane and ethylidenecyclopropane ($\Delta H^{\ddagger}$ = 39.8 kcal/mole).

An upper estimate for the degenerate rearrangement 37a $\rightleftharpoons$ 37b can be obtained from the work of Gajewski (3), from the conversion of trans-2,3-dimethylmethylenecyclopropane (46b) to 2-methylethylidenecyclopropane (46c).



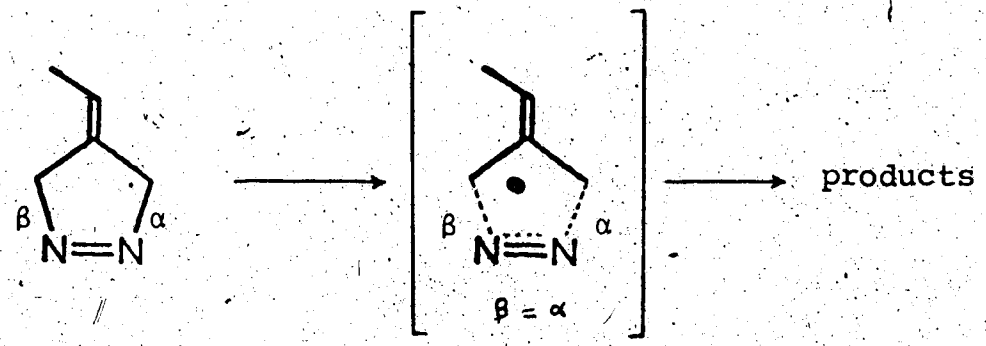
46b $\rightleftharpoons$ 46c

The activation parameters for this process are estimated by Gajewski to be at 152° $\Delta H^{\ddagger}$ = 36.3 kcal/mole and $10^{14.26}$ for the preexponential term. Since the addition of a methyl group generally lowers the activation energy of the carbon-carbon bond fission by approximately 2kcal/mole, we can use $\Delta H^{\ddagger}$ = 38.3 kcal/mole for the process 37a $\rightleftharpoons$ 37b. The calculated rate constant for this process at 152° is then $k = 3.69 \times 10^{-6}\ s^{-1}$ and the calculated amount of conversion after one hour is 1.3%.

On this basis, we can conclude that the observed product proportions for 37a and 37b has not significantly been affected by their interconversion.

DISCUSSION

It has not been possible, because of tautomerism, to run kinetic studies on 35 and 36. This is unfortunate for such studies would indicate whether the methylene groups are kept different because the bonds are not breaking in a truly concerted fashion (i.e. wherein the bond order for bonds α and β are reduced to the same fractional order in the rate determining transition state), or whether there is considerable asymmetry in the bond breaking process (i.e. α of lower order than β).

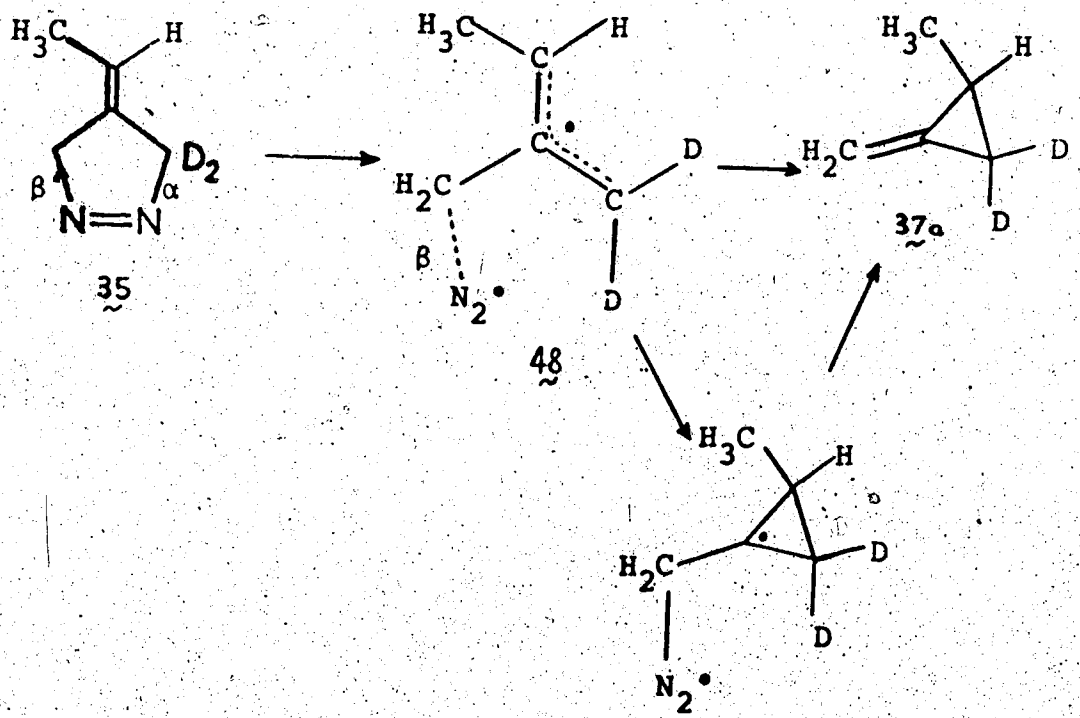


The results clearly indicate that the <u>syn</u>- and <u>anti</u>- methylenes cannot become equivalent. The discussion that follows is mechanistic speculation that relies upon the transfer of constraints from analogous 4-alkylidene-1-pyrazolines, and generally accepted principles such as the "least motion" principle and the laws of molecular dynamics. In testing these mechanistic hypotheses, we shall use the results of the

previous section to reduce the number of probable schemes, but merely note the unusual preference, previously cited (12), that the kinetically controlled products are 90% methylmethylenecyclopropane and 10% of the thermodynamically more stable ethylidenecyclopropane.

If we assume that bonds α and β are not breaking to exactly the same extent at the rate determining transition state, then it is reasonable to assume that α is of lower bond order than β since 3,3,5,5-tetramethyl-4-isopropylidene-1-pyrazoline (23) undergoes thermolysis at 1/32 the rate of 3,3,5,5-tetramethyl-4-methylene-1-pyrazoline (19).

This being the case, we would expect that allylic resonance would be most effective in bringing about such a cleavage and, as a result, the CD_2 of 35 will have rotated into the plane to give the species 48.



The major product observed for this reaction is 37a. This requires the rotation of the two allylic termini, the completion of the β C-N bond rupture and the formation of the exo-methylene double bond. This could be achieved by the electrocyclic ring closure of the allylic radical to the cyclopropyl radical. Such a step would be expected to be endothermic by approximately 40 kcal/mole*, thus it seems highly improbable that the diazenyl-cyclopropyl diradical would be on the reaction path.

It is possible that the breaking of the β C-N bond is concerted with the ring closure and thus, the principle product 37a is formed directly from 48.

If we assume that the minor product 37b arises from those occasions when the slower bond β is broken, then the ratio of products 37a/37b is the ratio k_α/k_β. The free energy difference ($\delta \Delta G^{\ddagger}$) for the formation of these products is given by the expression

$$RT \ln (k_\alpha/k_\beta) = \Delta G^{\ddagger}_\beta - \Delta G^{\ddagger}_\alpha = \delta \Delta G^{\ddagger}$$

If such a mechanism is valid, then we would expect deuterium substitution to increase the free energy of activation at the bond being broken by approximately 80 cal/mole per deuterium (23). This free energy change ($\Delta G^{\ddagger}_{d_2}$) for 35 and 36 is given by Equations 1 and 2.

---

*The cyclopropane ring strain is 27 kcal/mole and the loss of allylic resonance energy is 13 kcal/mole.

$$RT \ln (k_\alpha/k_\beta)_{\underset{\sim}{35}} = \delta \Delta G^{\ddagger} - \Delta G^{\ddagger}_{d_2} \qquad 1$$

$$RT \ln (k_\alpha/k_\beta)_{\underset{\sim}{36}} = \delta \Delta G^{\ddagger} + \Delta G^{\ddagger}_{d_2} \qquad 2$$

This could be the source of the different product proportions arising from $\underset{\sim}{35}$ and $\underset{\sim}{36}$ (see Tables Xa and XI). The value for $\Delta G^{\ddagger}_{d_2}$ may be estimated by subtracting Equation 2 from Equation 1 to give

$$RT \ln (k_\alpha/k_\beta)_{\underset{\sim}{35}} (k_\beta/k_\alpha)_{\underset{\sim}{36}} = -2\Delta G^{\ddagger}_{d_2}$$

Using the mean value for the product proportions in Tables Xa and XI, we find that

$$1.987 \times 433 \ln \left(\frac{75}{25}\right) \left(\frac{20}{80}\right) = -2\Delta G^{\ddagger}_{d_2}$$

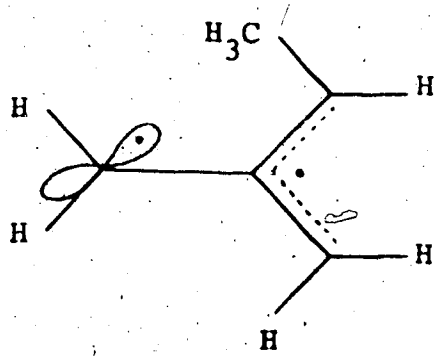
$$\text{Thus } \Delta G^{\ddagger}_{d_2} = 124 \text{ cal/mole}$$

By taking ±2% as the error on the mean value for the product proportions, the error on $\Delta G^{\ddagger}_{d_2}$ is ± 100 cal/mole.

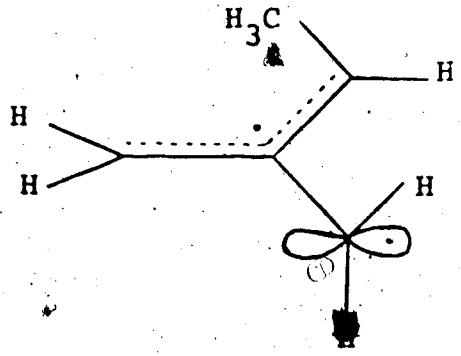
$$\Delta G^{\ddagger}_{d_2} = 124 \pm 100 \text{ cal/mole}$$

Because of the magnitude of this error, the result (62 ± 50 cal/mole per deuterium) may be considered to be fortuitously close and in the correct direction.

A second mechanistic alternative is that wherein one of the methylene groups is planar and one is othogonal as in 49a and 49b.



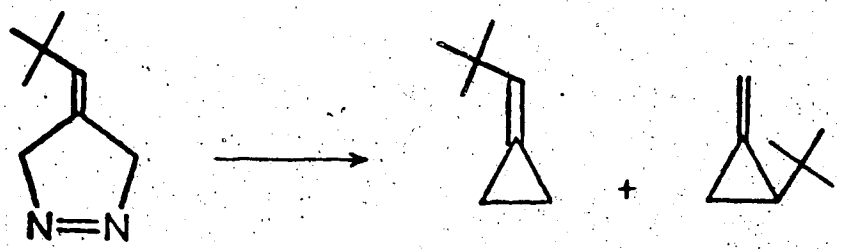
49a



49b

on the basis of generally observed steric factors, we would expect 49a to be more stable than 49b, and thus, from deuterium labelling, we would expect the ratio of 37a : 37b from 35 and 36 to be the inverse of that obtained.

Recently, H. Tokunaga (24) has prepared the 4-alkylidene-1- pyrazoline 50 and has observed that



50

4.8%

95.2%

95.2% of the methylenecyclopropane produced has the tert-butyl group on the ring. This observation is consistent with the mechanistic proposal that steric factors in the rupture of the C-N bonds α and β are important in determining the product proportions.

EXPERIMENTAL

All boiling points are uncorrected.

Gas chromatographic separation of the products was carried out on an Aerograph Autoprep Model A-700 gc connected to a Leeds and Northrup Model Speedomax H chart recorder. A 10 ft. column with 0.25 inch inner diameter, wall coated with 20% SF 96 on chromosorb W was used.

Nuclear magnetic resonance spectra were obtained using a Varian A-60 spectrometer and a Varian Model HA-100 spectrometer. Carbon-13 and deuterium nuclear magnetic resonance analyses were carried out on a Brucker HFX 90 spectrometer assisted by a 20K Nicolet 1085 computer.

Oil Bath. The temperature of the oil bath, in which the product studies were carried out, was controlled by a Melabs proportional temperature controller Model CTC-1A, and was measured by a Hewlett Packard Model 2801A quartz thermometer. The probe (Serial No. H/P 2850C 1239-02) was calibrated by the National Bureau of Standards. At 160°, the value of 0.01° was added to the readings as this was the linearity correction at that temperature. During the first run, the temperature could be held constant within ± 0.02° and during the second run, the temperature varied within ± 0.03°.

Thermolyses. For every run six breakseals of ca. 80 ml volume were filled with 150 µl of neat pyrazoline by vapor transfer. The pressure inside the breakseals at the temperature of the runs was calculated to be between 1 and 1.5 atmosphere. After heating, the breakseals were quickly quenched in ice-water.

The contents of one breakseal were vapor transferred into a receiver, $CDCl_3$ was added and an n.m.r. spectrum was taken. The contents of the other five breakseals were transferred into another receiver, chloroform was added to increase the ease of handling, and the products were separated by preparative gc.

Product Separation. Gas chromatographic separations of the products were performed by injecting up to 250 µl of sample. The column was kept at 35°C, the injection port at 125°C, the detector at 160°C and the collector at room temperature.

The retention times were 10 min. for the mixture of deuterated 2-methylmethylenecyclopropanes and 16 min. for the deuterated ethylidenecyclopropane.

Preparations

Crotyl Bromide was prepared according to the method of Claisen (16). Crotyl alchohol (500 g. 6.34 moles) and hydrobromic acid (2.3 ℓ, 48%) were mixed and stirred one day at room temperature. Then 2ℓ of cold water was added, the reaction mixture was stirred for 30 min. and transferred

to a separatory funnel. The lower layer was separated and dried over anhydrous sodium sulfate. After two distillations, the yield was 705 g (75%) bp 98-104° (lit. value 103-106° (16)).

1,2,3-Tribromobutane. The procedure was essentially that of Johnson and McEwan (25). Crotyl bromide (505 g, 3.74 moles) and dry carbon tetrachloride (750 ml) were placed in a 2 ℓ three-necked flask equipped with a stirring bar, a dropping funnel and a thermometer. The flask was chilled in an ice-salt mixture, and when the temperature reached -5°, bromine (200 cc, 3.92 moles, dried with concd. sulfuric acid) was added dropwise at such a rate that the temperature remained at about -5°. After the addition was over, the solution, orange-red in color, was allowed to warm up to room temperature, with continuous stirring overnight. The excess bromine and the carbon tetrachloride were distilled at atmospheric pressure in a 1 ℓ flask in which the solution was dropped from a funnel so that the flask was never more than two thirds full. The tribromobutane was twice distilled at 14 mm. The yield was 1015 g (92%) bp 103-105°/14-15 torr (lit. value 100-101°/14 torr (15)).

1,2-Dibromo-2-butene. 1,2,3-Tribromobutane was dehydrobrominated according to the procedure of Hurd and Meinert (15). In a 1 ℓ flask arranged for distillation was placed 480 g (1.63 mole) of 1,2,3 tribromobutane, 23 ml of water and

115 g of sodium hydroxide. The flask was heated with an oil bath and the contents were efficiently sitrred with a mechanical stirrer. Around 120°C, the reaction mixture became an emulsion and the product started to distill over. The oil bath temperature was raised up to 230° so that most of the product could distill at atmospheric pressure. The pressure was then lowered to 40 mm. in order to transfer any remaining product. The bromide in the receiving flask was washed with water and the bromide layer separated. After two distillations, the yield was 302 g (86%) bp 83-85°/ 3.85 torr (lit. value 85-90°/50 torr). The n.m.r. spectrum δ TMS ($CDCl_3$) showed signals for 80% 1,2-dibromo-2-butene: 6.23 (quartet, 1H), 4.28 (singlet, 2H), 1.65-1.95 (multiplet, 3H) and 20% 2,3-dibromo-1-butene: 6.0 (doublet, 1H), 5.57 (doublet, 1H), 4.78 (quartet, 1H) and 1.65-1.95 (multiplet, 3H).

Methylallene. The procedure was that of Hurd and Meinert (15). Absolute ethanol (620 ml) and zinc dust (344 g, 5.26 at.g) were placed in a 2 ℓ three-necked flask fitted with a mechanical stirrer, a dropping funnel, a nitrogen inlet and a condenser. The condenser was connected to a distilling flask which served as a trap. This flask was in turn connected to a receiver and both flasks were kept at dry-ice temperature. The ethanol was heated under reflux and 1-2-dibromo-2-butene (269 g, 1.26 mole), under nitrogen atmosphere, was added dropwise. The methylallene was trapped along with a small

amount of alcohol. After all the dibromide had been added, the alcohol in the flask was boiled for several minutes. Then the distilling flask was allowed to warm up to room temperature and heated to 35° in order to distill all of the methylallene. The yield was 48.5 g (72%). The n.m.r. spectrum δ TMS ($CDCl_3$) 5.06 (quartet, 1H), 4.63 (multiplet, 2H) and 1.64 (quintet, 3H).

Diazomethane-$\underline{d}_2$ (38). The procedure was essentially that of Hecht and Kozarich (17). First potassium t-butoxide was made by adding 60 g of freshly cut potsssium to 750 ml of dry t-butyl alcohol. The t-butyl alcohol was distilled off and the potassium t-butoxide was dried under vacuum. It was then hydrolysed with 125 ml of D_2O to produce t-butyl alcohol-$\underline{d}$ and potassium deuteroxide. The t-butyl alcohol was distilled off and 50 ml of D_2O was added to the dry potassium deuteroxide to make a 50% solution. Dry 1,2-dimethoxyethane (260 ml) was added and the mixture was cooled at -15°. N-nitrosomethylurea (61.8 g, 0.6 mole) was then added slowly, the temperature being kept under -10°. After the addition was over, the mixture was allowed to warm up to 0° and was stirred at that temperature for 2 hours. The reaction flask was then immersed in a dry-ice-acetone bath to freeze the water layer and the solution of diazomethane-$\underline{d}_2$ in 1,2-dimethoxyethane was decanted and dried over KOH pellets. The yield (as determined by titration with benzoic acid) was 0.26 mole (43%).

(E) -4-Ethylidene-1-pyrazoline-3,3-$\underline{d}_2$ (35). The solution of diazomethane-$\underline{d}_2$ in 1,2-dimethoxyethane (180 ml, 0.25 mole) was divided into two pressure bottles at dry-ice temperature. Methylallene (ca 35 g) was added to each. The bottles were allowed to warm up slowly to room temperature and were left undisturbed for 11 days until complete decolorization. The contents of the bottles were then poured into a distilling flask and ether and excess methylallene were distilled off at atmospheric pressure. 1,2-Dimethoxyethane was evaporated from the resulting solution using a rotary evaporator. Finally, the oily residue was distilled at reduced pressure bp 51-52°/ 10 torr. Yield 5.1 g (21%). The n.m.r. spectrum is shown in Figure 1.

trans-2-Buten-1-ol-1,1-$\underline{d}_2$ (40). The procedure of Schuetz and Millard (18) for the preparation of 2-propen-1-ol-1,1-$\underline{d}_2$ was adapted. A slurry of lithium aluminum deuteride (14.891 g, 0.354 mole) in 600 ml of dry ether was prepared under a nitrogen atmosphere and then chilled in an ice salt bath. A solution of crotonyl chloride (64 g. 0.612 mole) in 200 ml of ether was added to the stirred deuteride slurry at such a rate that the reaction temperature could be kept between -15 and -10°. After the acid chloride addition, the mixture was stirred at room temperature for 1 day and chilled again in an ice-salt bath. The reduction complex was then hydrolyzed by adding 20 ml of water, 20 ml of 15% sodium hydroxide, and

20 ml of water, dropwise and in that order. The precipitate that formed was removed by filtration and washed well with dry ether. The resulting ether solution was dried with sodium sulfate and concentrated by distillation through a Vigreux column. The concentrated solution was dried again over 4 Å molecular sieve and the rest of the ether was evaporated under reduced pressure. The product was then transferred under 0.5 torr into receivers cooled in dry-ice-acetone. The yield was 32.1 g (71%). The n.m.r. spectrum δ TMS ($CDCl_3$) 5.64 (multiplet, 2H), 2.93 (singlet, 1H), and 1.69 (doublet, 3H).

trans-1-Bromo-2-butene-1,1-d_2 (41). The bromide was prepared from the corresponding alcohol by the method of Kjaer et al. (19). A mixture of 34.6 g (0.468 mole) of trans-2-buten-1-ol-1,1d_2 and 4 g of pyridine was cautiously added dropwise to 43.1 g (0.16 mole) of phosphorus tribromide under nitrogen. The reaction flask was kept at room temperature with a water bath. After the addition was completed, the mixture was heated at 70° for 15 minutes. Distillation under reduced pressure gave 53.9 g (85%) of the bromide, bp 40-44°/84 torr. Actually, the equilibrium mixture of primary and secondary bromides described by Young and Winstein (26) was obtained. The n.m.r. spectrum δ TMS ($CDCl_3$) 5.76 (multiplet, 2H) and 1.78 (multiplet, 3H).

1,2,3-Tribromobutane-1,1-$\underset{\sim}{d}_2$ (42). Bromine (21.3 ml, 0.415 mole was added dropwise to a solution of trans-1-bromo-2-butene-1,1-$\underset{\sim}{d}_2$ (53.9 g, 0.393 m) in carbon tetrachloride (85 ml). The temperature in the flask was kept between -5 and -10°. After the addition of bromine was complete, the reaction mixture was stirred at room temperature for one hour. The excess bromine and carbon tetrachloride were distilled from the reaction flask at atmospheric pressure. The tribromide was then vacumm distilled. Yield 98.4 g (85%), bp. 102-104°/14 torr. The n.m.r. spectrum δ TMS ($CDCl_3$) 4.39 (multiplet, 2H) and 1.83 (doublet, 3H).

1,2-Dibromo-2-butene-1,1-$\underset{\sim}{d}_2$ (43). In a 250 ml three-necked flask fitted for distillation was placed 1,2,3-tribromobutane-1,1-$\underset{\sim}{d}_2$ (98.4 g, 0.331 mole), sodium hydroxide (23.3 g, 0.58 mole) and water (4.7 ml). The reagents were stirred with a mechanical stirrer and the flask was heated with an oil bath. At 140°, the mixture became an emulsion and the product started to distill. The temperature of the oil bath was raised to 170° so that the bulk of the product could distill at atmospheric pressure. Vacuum was then gradually applied in order to transfer the remainder of the product. The bromide was separated from the water layer and dried over magnesium sulfate. It was not further purified. Yield 50 g (70%). The n.m.r. spectrum δ TMS ($CDCl_3$) showed signals for 83% 1,2-dibromo-2-butene-1,1-$\underset{\sim}{d}_2$: 6.21 (quartet, 1H), 1.78 (multiplet, 3H) and 17% 2,3-dibromo-1-butene-1,1-$\underset{\sim}{d}_2$: 4.76 (quartet, 1H)

and 1.78 (multiplet, 3H).

1,2-Butadiene-1,1-$\underline{d}_2$ (39). The apparatus used was the same as that described for the synthesis of methylallene. It was evacuated three times and placed under a nitrogen atmosphere. Absolute ethanol (110 ml) and zinc dust (60.5 g, 0.93 at.g.) were placed in the 500 ml reaction flask. The reaction flask was heated with an oil bath and after the ethanol had started to reflux 1,2-dibromo-2-butene-1,1-$\underline{d}_2$ (50 g, 0.231 mole) was added dropwise. After the addition of bromide was completed, the mixture was stirred and refluxed for another half hour. The trapped crude product was distilled in order to separate the butadiene from ethanol. Yield 10.8 g (83%). The n.m.r. spectrum δ TMS ($CDCl_3$) 5.07 (quartet, 1H) and 1.65 (doublet, 3H).

(Z)-4-Ethylidene-1-pyrazoline-3,3-$\underline{d}_2$ (36). Diazomethane was prepared from bis-(N-methyl-N-nitroso)terephthalamide (54 g, 0.15 mole, 70% in mineral oil) according to the procedure of Moore and Reed (27). The resulting solution of diazomethane in ether (ca 100 ml) was placed in a pressure bottle at dry-ice temperature. 1,2-Butadiene-1,1-$\underline{d}_2$ (10.8 g, 0.193 mole) was added. The bottle was allowed to warm up to room temperature, and was left undisturbed until complete loss of the yellow color which took 10 days. The excess butadiene and ether were distilled at atmospheric pressure through a Vigreux column. The residue was then distilled at reduced pressure.

bp. 50-51°/10 torr. Yield 5.3 g (36%). The n.m.r. spectrum is shown in Figure 2.

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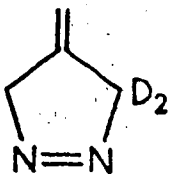
APPENDIX

SOME OF THE STRUCTURES DISCUSSED IN THIS THESIS



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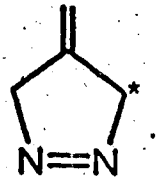

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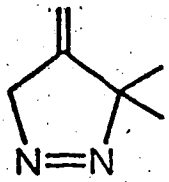

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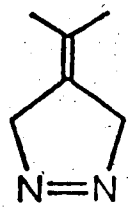

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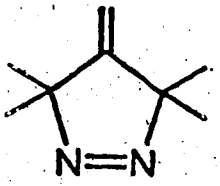

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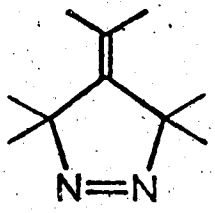

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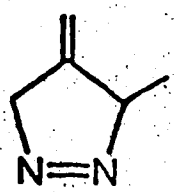

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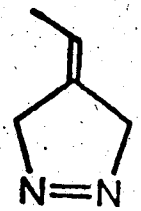

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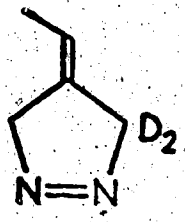

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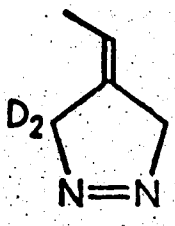

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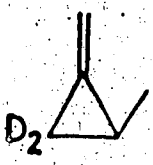

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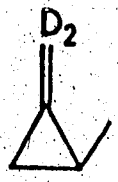

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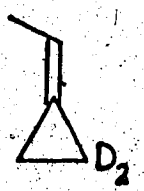

45a

45b

VITA

The author was born in Parthenay, France, on August 31, 1949. After graduation from high school in 1966, he entered the University of Poitiers in the Faculty of Science. In 1970 he graduated with a "Maitrise de Chimie". He then entered the "Ecole Superieure de Chimie Industrielle de Lyon" and graduated in 1972 as a chemical engineer. The same year he came to Canada with a Canada Council grant and entered the Faculty of Graduate Studies of the University of Alberta, Edmonton. He served as a part-time Graduate Teaching Assistant in Chemistry while completing his M.Sc. program.

In 1973 he married Catherine Paul and is now the father of one girl.