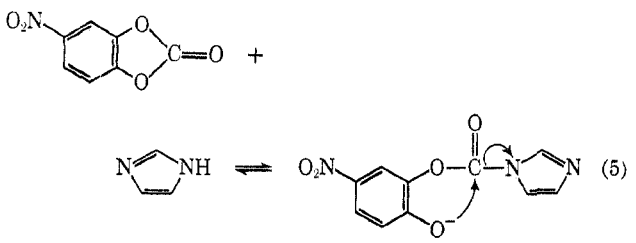
There would appear to be no reason why imidazole could not attack the cyclic ester as a nucleophile. The reason for a general base or kinetic equivalent mechanism must then be that the reaction cannot readily go forward to products when imidazole attacks as a nucleophile. This could be due to a rapid reclosure of the ring as in eq 5 to regenerate starting material.



The mechanism might therefore change to the normally less favorable general base pathway since the reaction would then go directly to products. This argument assumes that there is no great energy barrier for ring formation. Reversibility was not detected in the imidazole reaction with II at low concentrations of *p*-nitrophenol, but in an intramolecular reaction the effective concentration of the attacking group is greatly increased.[20]

The second-order rate constant for attack of imidazole on bis(4-nitrophenyl) carbonate at 30° is 144 times as large as k_{Im} for the cyclic carbonate at 30°, whereas the rate constant for water catalysis is 4 times as large at 30° for the cyclic ester as that for the noncyclic ester at 50°. Thus, the cyclic compound, while more reactive in the water-catalyzed reaction is much less susceptible to imidazole catalysis, in accord with the fact that a normally less favorable mechanism is involved.

Five- and six-membered ring lactones having a cis configuration are hydrolyzed with hydroxide ion catalysis much more rapidly than are lactones having a trans configuration or noncyclic esters.[21,22] Facile imidazole catalysis was observed in the hydrolysis of the cis lactones, γ-butyrolactone and δ-valerolactone,[23] but imidazole catalysis of the hydrolysis of aliphatic esters without acyl group activation can be detected as occurring at only an extremely slow rate.[24] Thus, the reactive cis configuration is enhancing imidazole catalysis of lactone hydrolysis. In the case of carbonate ester hydrolysis, however, as indicated in the present study, when reversibility of ring opening is likely on steric grounds imidazole catalysis will be less effective for esters in the cis configuration than for analogous noncyclic esters.

Registry No.—I, 25859-54-5; II, 5070-13-3; III, 25859-56-7; *p*-nitrophenyl chloroformate, 7693-46-1.

Acknowledgment.—This work was supported by The National Institutes of Health Research Grant GM-14357.

(20) W. P. Jencks, "Catalysis in Chemistry and Enzymology," McGraw-Hill, New York, N. Y., 1969, p 10-13.

(21) R. Huisgen and H. Ott, *Tetrahedron*, **6**, 253 (1959).

(22) T. C. Bruice and S. Benkovic, "Bioorganic Mechanisms," Vol. 1, W. A. Benjamin, New York, N. Y., 1966, p 22.

(23) T. C. Bruice and J. J. Bruno, *J. Amer. Chem. Soc.*, **83**, 3493 (1961).

(24) J. F. Kirsch and W. P. Jencks, *ibid.*, **86**, 833, 837 (1964).

Acid-Catalyzed Reactions of Certain δ-Hydroxyamides Having γ Hydrogen. Mechanisms[1a]

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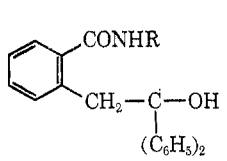
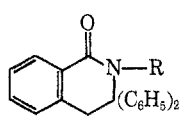
Certain δ hydroxyamides having γ hydrogen undergo three types of acid-catalyzed reactions; these involve cyclodeamination, linear dehydration, and cyclodehydration to form a δ lactone, an olefin–amide, and a δ lactam, respectively. The predominant course of reaction is dependent on the acidic medium, the temperature, and the structure of the hydroxyamide. The olefin–amide is evidently an intermediate in the conversion of certain hydroxyamides into lactams, but not in that of certain others. Mechanisms are suggested and the usefulness of the methods in synthesis are indicated.

Recently,[2] δ-hydroxyamides such as **1a** were shown to undergo cyclodehydration with cold concentrated sulfuric acid to furnish a useful method of synthesis of corresponding δ lactams, which are substituted 3,4-dihydroisocarbostyrils. Thus, **1a** afforded lactam **2a**. The hydroxyamides **1a** and **1b** are readily prepared by dilithiation of the appropriate N-substituted *o*-toluamide with *n*-butyllithium followed by condensation of the resulting dilithioamide with benzophenone.[3]



1a, R = CH_3
b, R = C_6H_5



2a, R = CH_3

In the present investigation, a study was made of the reactions and mechanisms of hydroxyamides such as **1a** with various acidic reagents. This study promised to be of interest because of the possibility of effecting two new types of acid-catalyzed reactions and of determining the mechanisms of all three types of reactions. Both new types of reaction were realized. Thus, hydroxyamides **1a** and **1b** underwent linear dehydration and cyclodeamination with appropriate acidic reagents to give olefin–amides **3a** and **3b** and lactone **4**, respectively. Also, olefin–amide **3a** under-

(1) (a) Supported by the National Science Foundation. (b) Deceased.

(2) C. L. Mao, I. T. Barnish, and C. R. Hauser, *J. Heterocycl. Chem.*, **6**, 83 (1969).

(3) R. L. Vaulx, W. H. Puterbaugh, and C. R. Hauser, *J. Org. Chem.*, **29**, 3514 (1964).

TABLE I

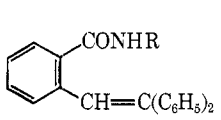
ACID-CATALYZED REACTIONS OF δ-HYDROXYAMIDES 1a AND 1b OR OLEFIN–AMIDES 3a AND 3b

Expt no.	Hydroxyamide or olefin–amide	Acid reagent	Reaction temp, °C	Reaction time, hr	Product	Yield, %
1	1a	HOAc	20–30	240	Lactone 4	*a*
2	1a	HOAc	Reflux	4–12	Lactone 4	80–88
3	1a	HCl–HOAc[b]	20–30	4	Olefin 3a	89
4	1a	HOAc–H_2SO_4[c]	20–30	4	Olefin 3a	63
5	1a	HOAc–H_2SO_4[c]	20–30	1344	3a + 2a	75[d]
6	1a	HOAc–H_2SO_4[c]	Reflux	0.4	Lactam 2a	85
7	1a	BTDA[e]	20–30	4	Olefin 3a	41
					Lactam 2a	16
8	1a	BTDA[e]	Reflux	1	Lactam 2a	62
9	1a	H_2SO_4	0	2	Lactam 2a	54[f]
10	1a	H_2SO_4	20–30	2	Lactam 2a	58
11	3a	HCl–HOAc[b]	Reflux	0.5	Lactam 2a	78
12	3a	HOAc–H_2SO_4[c]	20–30	168	Lactam 2a	*g*
13	3a	HOAc–H_2SO_4[c]	Reflux	0.5	Lactam 2a	96
14	3a	H_2SO_4	0	2	Lactam 2a	75
15	1b	HOAc	Reflux	12	Lactone 4	91
16	1b	HCl–HOAc[b]	20–30	4	Olefin 3b	88
17	1b	HOAc–H_2SO_4[c]	20–30	4	Olefin 3b	73

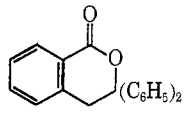
[a] Lactone 4 was obtained mixed with much recovered 1a; the ratio was 15:85 (by nmr). [b] Acetic acid saturated with hydrogen chloride gas. [c] Acetic acid containing a few drops of concentrated sulfuric acid. [d] Ratio of 3a to 2a was 41 to 59 (by nmr). [e] Boron trifluoride–diacetic acid complex. [f] Reference 2. [g] Lactam was obtained mixed with recovered olefin 3a; the ratio of 2a:3a was 57:43 (by nmr).

went acid-catalyzed cyclization to afford δ lactam 2a. The results are summarized in Table I.

Table I shows that hydroxyamide 1a afforded exclusively lactone 4 with acetic acid (expt 1 and 2), but produced the olefin–amide 3a and/or lactam 2a with



3a, R = CH_3
b, R = C_6H_5

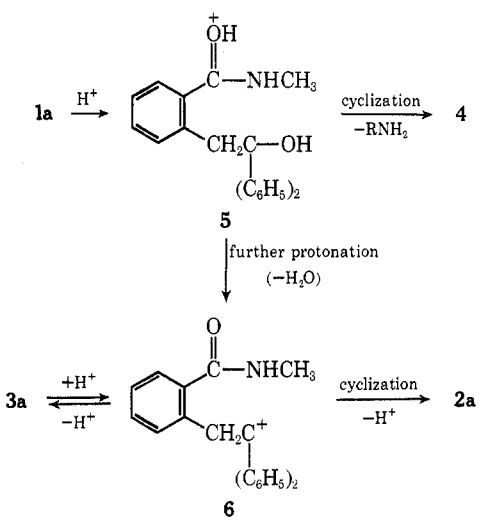


4

the stronger acids, hydrogen chloride gas or a little sulfuric acid in acetic acid (expt 4–6), boron trifluoride–diacetic acid complex (BTDA) (expt 7 and 8), and concentrated sulfuric acid (expt 9 and 10). The effective acid with the hydrogen chloride or sulfuric acid in acetic acid would presumably be $CH_3COOH_2^+$, and that in BTDA might be $CH_3COO \rightarrow BF_3H^+$, $H^+-BF_3OCOCH_3$, or BF_3. Consequently, olefin–amide 3a must be an intermediate in the conversion of hydroxyamide 1a into lactam 2a by $CH_3COOH_2^+$ and BTDA; the formation of olefin–amide 3a is evidently kinetically controlled, and that of lactam 2a thermodynamically controlled. Although olefin–amide 3a was not isolated in the reaction with sulfuric acid, it was shown to be converted into lactam 2a by this acid (expt 14); therefore 3a may also be an intermediate when this acid is employed. Insofar as studied, the results obtained with hydroxyamide 1b are similar to those with 1a (see expt 15–17, Table I).

On the basis of these results, the mechanisms represented in Scheme I are suggested. The mechanism of cyclodeamination to form lactone 4 presumably involved protonation of the oxygen at the amide group to form cation 5,[4] which undergoes cyclization accompanied by elimination of methylamine.[5] That the present cyclodeamination is not merely a thermal reaction as observed previously at 180–190°[3] was indicated by almost quantitative recovery of hydroxyamide 1a after refluxing it in *n*-amyl alcohol, which boils 20° higher than acetic acid.

SCHEME I



The mechanisms of the linear dehydration and the cyclodehydration of hydroxyamide 1a presumably involve protonation of the hydroxyl oxygen to form carbonium ion 6 which may be a common intermediate in the formations of olefin–amide 3a and lactam 2a. Thus, carbonium ion 6 may lose a linear proton to produce 3a or undergo cyclization accompanied by loss of the proton on nitrogen to give 2a (see Scheme I).

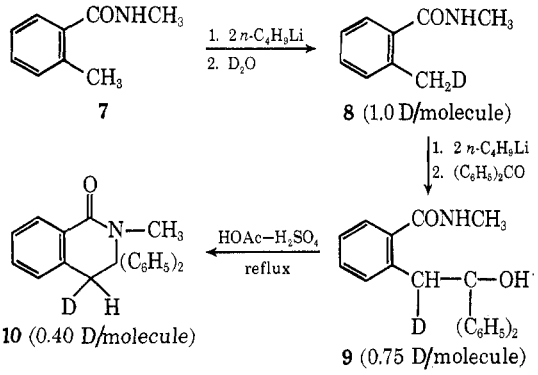
That at least some of lactam 2a arises through olefin–amide 3a was supported by loss of some deuterium on acid-catalyzed cyclodehydration of deuteriohydroxyamide 9. For example, deuteriohydroxyamide 9,

(4) Although protonation at either the amide nitrogen or oxygen should catalyze lactone formation, only the latter protonation is shown in Scheme I; see A. R. Katritzky, and R. A. Y. Jones, *Chem. Ind.*, (London), 722 (1961).

(5) See C. L. Mao, I. T. Barnish, and C. R. Hauser, *J. Heterocycl. Chem.*, 6, 475 (1969).

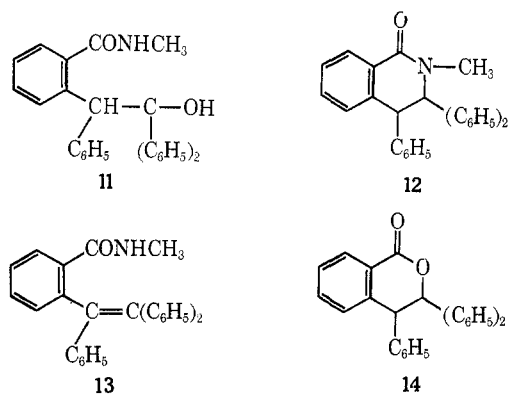
prepared from **7** through **8**, underwent cyclodehydration with a little sulfuric acid in acetic acid ($HOAc-H_2SO_4$) to form lactam **10**, containing less deuterium (Scheme II). Lactam **10** was shown to retain all of its

SCHEME II



deuterium under such conditions. Similar results were obtained from deuteriohydroxyamide **9** containing 1.0 D/molecule and concentrated sulfuric acid (see Experimental Section).

Similarly, δ-hydroxyamide **11**, which has recently been shown to undergo cyclodehydration with cold sulfuric acid to form lactam **12**,[2] underwent linear dehydration with a little sulfuric acid in acetic acid ($HOAc-H_2SO_4$) and cyclodeamination with acetic acid to give olefin–amide **13** and lactone **14**, respectively. However, in contrast to olefin–amide **3a**, olefin–amide **13** failed to undergo cyclization with either $HOAc-H_2SO_4$ or concentrated sulfuric acid. Also, hydroxyamide **11** afforded only olefin–amide **13**, not lactam **12**, with refluxing $HOAc-H_2SO_4$, which readily produced the lactam from hydroxyamide **1a** (see Table I).

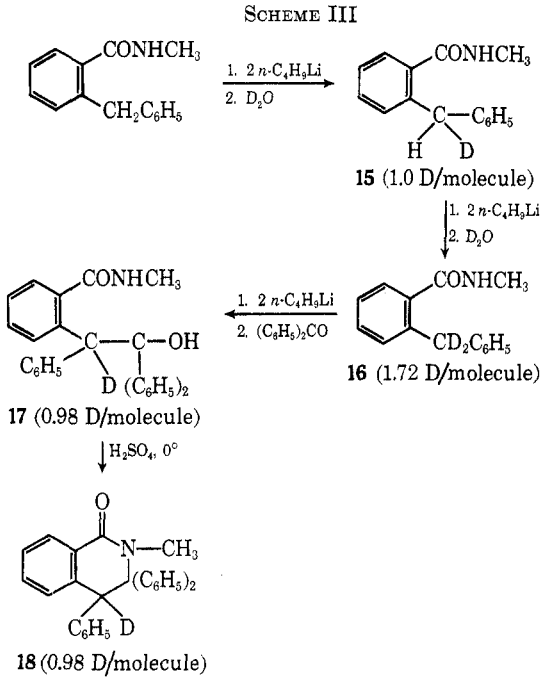


Interestingly, in contrast to deuteriohydroxyamide **9**, deuteriohydroxyamide **17** underwent cyclodehydration with cold concentrated sulfuric acid to form deuteriolactam **18** without loss of deuterium. This result and the preparation of deuteriohydroxyamide **17** through deuteriohydroxyamides **15** and **16** are shown in Scheme III. The reaction of deuteriohydroxyamide **17** with $HOAc-H_2SO_4$ was not studied since only the olefin–amide would have resulted (see above).

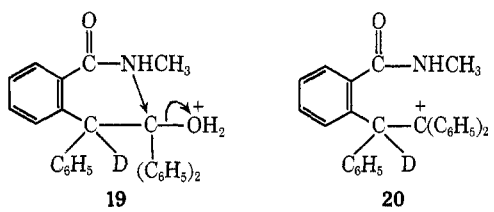
Two explanations for this result seem possible. One would involve the concerted mechanism represented in **19**,[6] and the other the irreversible conversions of

(6) This mechanism was suggested recently in a preliminary report, see C. L. Mao, F. E. Henoch, and C. R. Hauser, *Chem. Commun.*, 1595 (1968).

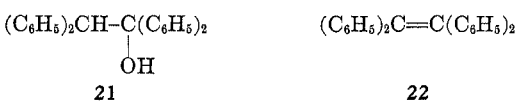
SCHEME III



carbonium ion **20** to deuteriolactam **18** and olefin–amide **13**.



Incidentally, carbinol **21**, which is related to hydroxyamide **11**, but has no amide group, has been reported to undergo acid-catalyzed linear dehydration by a concerted mechanism to form olefin **22**.[7]



Discussion

The present realization of three different types of acid-catalyzed reactions of a single compound, a δ-hydroxyamide, seems rather remarkable. Although two of the three courses of reaction, those involving linear dehydration and cyclodehydration, are both initiated by protonation of the hydroxyl oxygen leading to formation of a common carbonium ion, **6** and **20**, the subsequent courses of the two reactions are different. Moreover, the linear loss of a proton from carbonium ion **6** is reversible (see Scheme I) whereas that from carbonium ion **20** is apparently not.

The predominant course of reaction observed with a hydroxyamide is dependent on the acidic reagent and temperature employed (see Table I). Although the structure of the hydroxyamide also may be important (compare **1a** and **1b** with **11**), the present results indicate that, at least for hydroxyamides **1a** and **1b** and **11**, the acetic acid method is more convenient than the earlier thermal procedure for cyclodeamination, and

(7) A. Gandini and P. H. Plesch, *J. Chem. Soc.*, 6019 (1965).

that the HOAc–H_2SO_4 reagent is preferable to the previous concentrated sulfuric acid method for cyclodehydration (see Table I). Also, the HOAc–H_2SO_4 or HCl–HOAc reagent is the reagent of choice for linear dehydration. Besides these synthetic methods, those involved in preparations of the deuterio derivatives should be useful.

Experimental Section[8]

The results of acid-catalyzed reactions of δ-hydroxyamides **1a** and **1b**[3] or olefin–amides **3a** and **3b** are summarized in Table I. In each case, the reaction mixture was poured into ice–water and the crude product was removed by filtration and recrystallized from an appropriate solvent. The experimental details are described below.

Cyclodeamination of δ-Hydroxyamides 1a and 1b.—Solutions of 0.5–1.0-g samples of **1a** in 10 ml of acetic acid (HOAc) were refluxed for 4 and 12 hr to give lactone **4**, mp and mmp 145–146° (EtOH–H_2O) (lit.[3] mp 144–144.5°), in yields of 80 and 88%, respectively.

To show that this was not a thermal cyclodeamination,[3] a 1.0-g sample of hydroxyamide **1a** was refluxed in *n*-amyl alcohol for 12 hr. There was recovered 0.95 g (95%) of the original hydroxyamide **1a**.

Similarly, treatment of **1b** (1.0 g) in 15 ml of HOAc gave 0.7 g (91%) of lactone **4**, mmp 144–146°.

Linear Dehydration of δ-Hydroxyamides 1a and 1b. A. With Hydrogen Chloride in Acetic Acid (HCl–HOAc).—A 0.5-g sample of **1a** in 20 ml of HOAc saturated with dry HCl gas was stirred at room temperature for 4 hr. The yellow solution was worked up to give, after one recrystallization from CH_3CN, 0.42 g (89%) of olefin–amide **3a**: mp 202–204°; ir 3300 (NH) and 1640 cm^{-1} (C=O); nmr ($CDCl_3$) δ 2.85 (s, 3, CH_3N) and 7.25 (m, 15, ArH).

Anal. Calcd for $C_{22}H_{19}NO$: C, 84.31; H, 6.11; N, 4.47. Found: C, 84.29; H, 6.05; N, 4.54.

Likewise, treatment of a 1.0-g sample of **1b** with HCl–HOAc at room temperature afforded 0.84 g (88%) of olefin–amide **3b**, mp 151–153°, ir 3310 (NH) and 1635 cm^{-1} (C=O).

Anal. Calcd for $C_{27}H_{21}NO$: C, 86.37; H, 5.64; N, 3.73. Found: C, 86.17; H, 5.90; N, 3.79.

B. With Acetic Acid Containing Sulfuric Acid (HOAc–H_2SO_4).—A 1.0-g sample of **1a** or **1b** in 20 ml of acetic acid containing a few drops of concentrated sulfuric acid (HOAc–H_2SO_4) was stirred at room tempersture for 4 hr. The yellow solution was worked up as usual to afford 0.6 g (63%) of olefin–amide **3a**, mp 201–203°, or 0.7 g (73%) of olefin–amide **3b**, mp 151–153°, respectively.

C. With Boron Trifluoride–Diacetic Acid Complex (BTDA).—A 2.0-g sample of **1a** was treated with 20 ml of BTDA at room temperature for 4 hr. The amber-colored solution was poured into ice water and the aqueous mixture was neutralized with solid $NaHCO_3$. The crude product was removed by filtration to give 1.5 g of yellowish solid, mp 160–180°. Trituration of the crude product with 20 ml of hot CH_3CN left 0.8 g (41%) of insoluble olefin–amide **3a**, mp 202–204°. The hot CH_3CN solution was cooled in an ice bath to give 0.31 g (16%) of lactam **2a**, mp and mmp 196–198° (lit.[3] mp 196–198°).

Cyclodehydration of δ-Hydroxyamide 1a. A. With HOAc–H_2SO_4.—A 1.0-g sample of **1a** in 20 ml of HOAc–H_2SO_4 was refluxed for 25 min. The crude product was recrystallized from CH_3CN to give 0.81 g (85%) of lactam **2a**.

B. With BTDA.—A 2.0-g sample of **1a** in 20 ml of BTDA was heated at reflux for 1 hr to give 1.2 g (62%) of lactam **2a**, mp 196–198°.

C. With Concentrated Sulfuric Acid (H_2SO_4).—A 1.0-g sample of **1a** was slowly dissolved in 10 ml of H_2SO_4 at room temperature. After 2 hr the orange-red solution was worked up to give 0.52 g (85%) of lactam **2a**, mp and mmp 196–198°.

Similarly, treatment of **1a** with H_2SO_4 at 0° gave lactam **2a** in 52% yield.

Cyclization of Olefin–Amide 3a to Form Lactam 2a. A. With HCl–HOAc.—A 0.5-g sample of **3a** in 20 ml of HCl–HOAc was refluxed for 1 hr to give 0.39 g (78%) of lactam **4a**, mp 196–198° (CH_3CN).

In another experiment, the reaction mixture was refluxed for 30 min to give a mixture of lactam **2a** and the starting olefin–amide **3a** (detected by ir).

B. With HOAc–H_2SO_4.—A 0.3-g sample of olefin–amide **3a** in 10 ml of HOAc–H_2SO_4 was refluxed for 30 min. There was isolated 0.29 g (96%) of lactam **2a**, mp 196–198°.

C. With Concentrated Sulfuric Acid (H_2SO_4).—A 0.2-g sample of **3a** was slowly dissolved in 10 ml of H_2SO_4 at 0° for 2 hr. After recrystallization from CH_3CN, there was obtained 0.15 g (75%) of lactam **2a**, mmp 196–198°.

A similar result was obtained when olefin–amide **3a** was treated with H_2SO_4 at room temperature.

Preparation of Deuterio Derivatives of δ-Hydroxyamides 1a.—To 0.02 mol of dilithioamide, prepared from 0.02 mol of N-methyl-*o*-toluamide and 0.04 mol of *n*-butyllithium in THF–hexane[2] at 0°, was added 3 ml of deuterium oxide. After 20 min of stirring, 100 ml of cold water was added. The layers were separated and the crude product was recrystallized from hexane–benzene to give deuterio compound **8** in 75% yield; the compound contained 1.0 D/molecule by nmr.

To 0.005 mol of deuterioamide **8** in 20 ml of THF at 0°, was added 0.011 mol of *n*-butyllithium in hexane and the mixture was treated, after 30 min, with 0.005 mol of benzophenone in 10 ml of THF. The reaction mixture was worked up to give deuteriocarbinolamide **9** in 60% yield, containing 0.75 D/molecule.

In another experiment, deuterioamide **9**, containing 1.0 D/molecule was obtained by repeated deuteration of amide **7** followed by condensation with benzophenone.

Cyclization of 9 to Form 10. A. With HOAc–H_2SO_4.—A 1.0-g sample of **9** was dissolved in 20 ml of HOAc–H_2SO_4 and the mixture refluxed for 20 min. The orange solution was worked up to afford 0.56 g (60%) of lactam **10**, containing 0.4 D/molecule.

B. With H_2SO_4.—The treatment of 0.5 g of amide **9** (1.0 D/molecule) with 10 ml of H_2SO_4 acid at 0° for 2 hr and at 20–30° for 0.5 hr afforded of lactam **10**, (0.3–0.4 g), which contained 0.77 D/molecule and 0.50 D/molecule.

Linear Dehydration of δ-Hydroxyamide 11.—A 0.4-g sample of amide **11** was stirred with 20 ml of HOAc–H_2SO_4 at room temperature for 5 hr. The yellow mixture was worked up giving 0.3 g of crude product, mp 270–274°. After one recrystallization from CH_3CN–DMF, there was obtained 0.21 g (55%) of pure olefin–amide **13**: mp 274–275°; ir 3320 (NH) and 1630 cm^{-1} (C=O).

Anal. Calcd for $C_{28}H_{23}NO$: C, 86.34; H, 5.96; N, 3.60. Found: C, 86.25; H, 6.03; N, 3.53.

In another experiment, a 0.5-g sample of amide **11** in 20 ml of HOAc–H_2SO_4 was refluxed for 4 hr. The reaction mixture was worked up to give 0.4 g (83%) of olefin–amide **13**, mmp 273–275°. No lactam **12** was isolated.

Attempted Cyclization of Olefin–Amide 13 to Form Lactam 12. A. With HOAc–H_2SO_4.—A 0.5-g sample of olefin–amide **13** was refluxed with 20 ml of HOAc–H_2SO_4 for 4 hr. The resulting yellow solution was worked up to afford 0.45 g (90%) of the starting olefin–amide **13**, mmp 274–275°. None of the lactam **12** was detected (by nmr).

B. With H_2SO_4.—A 0.5-g sample of olefin–amide **13** was slowly dissolved in 10 ml of H_2SO_4 at 0° during 1 hr. The yellow solution was poured onto ice water and the clear aqueous solution was carefully neutralized with solid $NaHCO_3$. The aqueous solution was then extracted with ether. Evaporation of the ethereal extract gave no residue. Neither the lactam **12** nor the starting olefin–amide **13** was isolated. Apparently, water soluble material was formed.

Preparation of Deuterio Derivatives.—To 0.02 mol of the dilithio derivative of δ-hydroxyamide **11** in THF–hexane was added 3 ml of deuterium oxide. After 20 min of stirring, 100 ml of water was added to it. The layers were separated and the crude product was recrystallized from aqueous ethanol to give deuterio compound **15** in 80% yield. The nmr determination showed that this compound contained 1.0 D/molecule.

A 0.01-mol portion of deuterioamide **15** was again treated with with *n*-butyllithium and followed by deuterium oxide to give

(8) Melting points were taken on Thomas–Hoover capillary melting point apparatus and are uncorrected. Ir spectra were determined on a Perkin-Elmer Infracord Model 137 or 237 in KBr disks. Nmr spectra were obtained with a Varian Associates A-60 spectrometer using tetramethylsilane as internal standard. Analyses were preformed by M-H-W Laboratories, Garden City, Mich. *n*-Butyllithium was obtained from Foote Mineral Company, Exton, Pa. Tetrahydrofuran (THF) was freshly distilled from lithium aluminum hydride.

deuterioamide **16** in 75% yield. The nmr spectrum of this compound was shown to consist of 1.72 D/molecule.

To 0.005 mol of deuterioamide **16** in 20 ml of THF at 0° was added 0.011 mol of *n*-butyllithium in hexane and the mixture was treated, after 30 min, with 0.005 mol of benzophenone in 10 ml of THF. The reaction mixture was worked up to give deuteriocarbinolamide **17** in 60% yield. This amide was shown to contain 0.98 D/molecule.

Cyclization of 17 to Form 18.—A sample of deuteriocarbinolamide **17** (1.0 g) was dissolved in 5 g of H_2SO_4 at 0° for 20 min. The reaction mixture was poured onto ice and the solution was made basic with NaOH. The crude product was collected and recrystallized from CH_3CN to give 0.56 g (58%) of **18**, mp 190–192°, containing 0.98 D/molecule (by nmr). A similar result was obtained after repeating the experiment.

Cyclodeamination of γ-Hydroxyamide 11.—As in the case of cyclodeamination of **1a**, a 1.0-g sample of **11** was refluxed with 50 ml of acetic acid overnight (*ca.* 12 hr). The product was worked up and recrystallized from aqueous DMF to give 0.62 g (65%) of 3,3,4-triphenyl-3,4-dihydroisocoumarin (**14**), mp 265–267°, ir 1720 cm^{-1} (C=O).

Anal. Calcd for $C_{27}H_{20}O_2$: C, 86.14; H, 5.35. Found: C, 85.93; H, 5.17.

Registry No.—**1a**, 2594-59-4; **1b**, 21868-83-7; **2a**, 20141-85-9; **3a**, 24097-53-8; **3b**, 24097-54-9; **13**, 24097-55-0; **14**, 24097-56-1.

Pyrolysis of Alkenylidenecyclopropane and Biscyclopropylidene Systems[1a]

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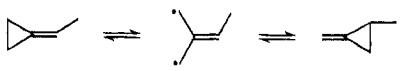
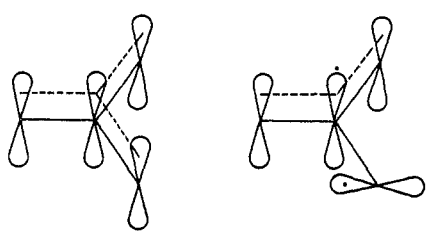
Pyrolysis of 1-(2-methylpropenylidene)-2,2,3,3-tetramethylcyclopropane (**3**) gives, in good yield, 1,2-(bis-isopropylidene)-3,3-dimethylcyclopropane (**4**). The synthesis of 1,1,2,2,5,5-hexamethylbiscyclopropylidene (**15**) was accomplished by the reaction of **3** with excess methylene iodide/zinc–copper couple. Pyrolysis of **15** at 400° in a flow pyrolysis system produces 1-isopropylidene-2,2,4,4-tetramethylspiropentane (**20**) while at higher temperatures **15** leads to 2,4,5-trimethyl-3-isopropylidenehexa-1,4-diene (**21**) as well as *o*- and *p*-xylene. Pyrolysis of 1-methylene-2-isopropylidene-3,3,4,4-tetramethylcyclobutane (**29**) at 460° leads cleanly to triene **21**. At 620° **4** gives enyne **13** as well as *p*-xylene and toluene. The mechanistic details of these transformations are discussed in terms of diradical intermediates.

The thermal rearrangement of methylenecyclopropanes has been known for a number of years. One of the first examples was the thermolysis of Feist's ester which has been studied by Ettlinger.[2] A number of examples have since been reported which indicate that the rearrangement proceeds *via* a trimethylenemethane diradical.[3] This is illustrated below for a simple case. Gajewski[4] has recently looked at optically active methylenecyclopropanes and concluded that, in substituted



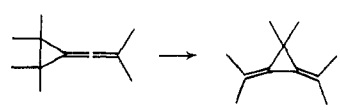
methylenecyclopropanes, the intermediate is not the planar delocalized diradical **1** but rather an orthogonal diradical represented as **2**. Consideration of these



1 **2**

results suggests that a similar rearrangement may obtain in more complicated methylenecyclopropyl systems. This report concerns itself with alkenylidenecyclopropane and biscyclopropylidene thermal chemistry.

A simple entry into the alkenylidenenecyclopropane system can be effected through reaction of allenic[5] or propargylic[6] halides with *tert*-butoxide in the presence of olefins. Synthesis of **3** was achieved in good yield by reaction of 1-bromo-3-methylbuta-1,2-diene with tetramethylethylene. Pyrolysis of **3**, carried out in a flow system at 360° (0.1 mm), results in an almost quantitative conversion to dimethylenecyclopropane **4**. A



3 **4**

similar and more instructive conversion was effected by thermolysis of alkenylidenecyclopropane **5**. Three isomeric hydrocarbons, **6**, **7**, and **8** were produced. The ratio of these products varies with temperature; the **6**:**7**:**8** ratio is 10:2:3 at 360° and 2:3:6 at 410°. Furthermore, pyrolysis of either **6** or **7** at 380° yields a mixture of the three isomeric compounds. On the other hand, **8** is recovered essentially unchanged at this temperature. Raising the temperature to 460°, however, causes partial transformation of **8** to **6** and **7**. The structural assignments of **6**, **7**, and **8** have been discussed previously.[7]

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