steric factors. Thus, the higher stability of unhindered amine–isocyanate complexes will not be shown by measurement of the basicity of the amine toward a proton.

An increased catalytic activity of the sterically unhindered triethylenediamine could also be expected even if the concentration of its complex were not larger than the concentration of the hindered amine complex, provided the velocity constant for the reaction involving this complex is larger than that involving the complex formed from the hindered amines.

As far as the mechanism of the water–isocyanate reaction is concerned, there is no reason to assume that this reaction occurs according to a mechanism different from the one operative in the reaction with the alcohol. The observed increase in the second-order rate constant during the reaction might be due to a catalytic effect of the ureides formed in this reaction; it is planned to check into this point.

Acknowledgment.—The authors are indebted to Dr. G. A. Mills and Mr. J. B. Maerker for their interest in this work. The infrared measurements were carried out by A. E. Creamer.

MARCUS HOOK, PENNA.

[CONTRIBUTION FROM FRICK CHEMICAL LABORATORY, PRINCETON UNIVERSITY]

Abnormal Beckmann Rearrangement of Spiroketoximes in Polyphosphoric Acid

BY RICHARD K. HILL AND ROBERT T. CONLEY[1]

RECEIVED APRIL 29, 1959

The Beckmann rearrangement of spiroketoximes having the spiro atom alpha to the oxime carbon has been carried out under various conditions. Using thionyl chloride or phosphorus pentachloride, most yielded mixtures of the normal lactam product and the product of a "second-order" cleavage, an unsaturated nitrile. The rearrangement of spirocyclopentanone oximes in polyphosphoric acid led in high yield to bicyclic α,β-unsaturated ketones, which were shown to result from acid-catalyzed cyclization of the unsaturated nitriles. Under these conditions, spirocyclohexanone oximes yielded, besides α,β-unsaturated ketones, small amounts of lactams and larger quantities of saturated amides. Spiro-[cyclopentane-1,2′-pseudo-indoxyl] oxime was cleaved by polyphosphoric acid to cyclopentanone and anthranilamide.

Among the classes of ketoximes which undergo "abnormal" reactions when subjected to Beckmann rearrangement conditions are those completely substituted at an α-carbon atom; these oximes often cleave to unsaturated nitriles or to mixtures of olefin and nitrile.[2,3] A striking feature of the reaction is the dependence of its course upon the particular reagent employed. α-Phenylisobutyrophenone oxime, for example, rearranges to dimethyl phenylacetanilide with hydrogen chloride in acetic acid, but is cleaved by thionyl chloride to benzonitrile and α-methylstyrene.[2j] Pivalophenone oxime yields three different products,[2b,4] depending on the reagent: hydrogen chloride in acetic acid yields pivanilide, benzenesulfonyl chloride in alkali produces *t*-butylbenzamide, and phosphorus pentachloride cleaves the molecule to benzonitrile. The situation is complicated, of course, by the geometrical isomerization of many oximes in either acidic or alkaline media.[5] Brown and co-workers[4] have explained the results with pivalophenone oxime by showing that a preliminary isomerization of the oxime is likely in the hydrogen chloride reaction, while the propensity of phosphorus pentachloride to cause scission is probably due to the very rapid dissociation of the oxime chlorophosphate. In general, aryl sulfonyl chlorides in alkali or pyridine have been the preferred reagents for effecting the normal rearrangement of these oximes.[3a,b] Whether polyphosphoric acid (PPA), which was shown to suppress many of the other abnormal reactions of oximes,[6] also brings about normal rearrangement of oximes of this type is not known, except for one case recently reported by Bruson and co-workers.[3d]

An interest in the preparation of some simple spiroamines led us to investigate the rearrangement of the oxime of spiro[4,5]decanone-1 (Ic) with different reagents in the hope of finding conditions which might lead to the lactam IIb.[7] The results obtained were interesting enough that several related ketones (Ia–e) were prepared and their oximes rearranged.[8]

Synthesis of the spiroketones followed standard routes. Compounds Ia and Id were prepared by pinacol rearrangement of 1,1′-dihydroxybicyclobutyl and 1,1′-dihydroxybicyclopentyl, respectively. Contraction of the ketone ring in Id by

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[1] Taken, in part, from the Ph.D. thesis of R. T. Conley, Princeton University, 1956.

[2] (a) R. Leuckart and E. Bach, *Ber.*, **20**, 104 (1887); (b) G. Schroeter, *ibid.*, **44**, 1201 (1911); (c) O. Wallach, *Ann.*, **259**, 309 (1890); (d) W. H. Perkin, Jr., and A. F. Titley, *J. Chem. Soc.* **119**, 1089 (1921); (e) W. H. Glover, *ibid.*, **93**, 1285 (1908); (f) C. C. Price and G. P. Mueller, THIS JOURNAL, **66**, 634 (1944); (g) P. D. Bartlett and M. Stiles, *ibid.*, **77**, 2806 (1955); (h) M. J. Hatch and D. J. Cram, *ibid.*, **75**, 38 (1953); (i) W. L. Bencze and M. J. Allen, *J. Org. Chem.*, **22**, 352 (1957); (j) R. E. Lyle and G. G. Lyle, *ibid.*, **18**, 1058 (1953); (k) R. E. Lyle, H. L. Fielding, G. Canquil and J. Rouzand, *ibid.*, **20**, 623 (1955).

[3] For exceptions, see (a) B. M. Regan and F. N. Hayes, THIS JOURNAL. **78**, 639 (1956); (b) S. Kaufmann, *ibid.*, **73**, 1779 (1951); (c) W. D. Burrows and R. H. Eastman, *ibid.*, **79**, 3756 (1957); (d) H. A. Bruson, F. W. Grant and E. Bobko, *ibid.*, **80**, 3633 (1958).

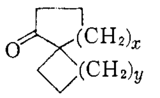
[4] R. F. Brown, N. M. van Gulick and G. H. Schmid, *ibid.*, **77**, 1094 (1955).

[5] (a) P. W. Neber, K. Hartung and W. Ruopp, *Ber.*, **58**, 1234 (1925); (b) R. S. Montgomery and G. Dougherty, *J. Org. Chem.*, **17**, 823 (1952).

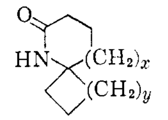
[6] E. C. Horning, V. L. Stromberg and H. A. Lloyd, THIS JOURNAL, **74**, 5153 (1952).

[7] A better synthetic route to these spirolactams was subsequently developed, starting with nitrocycloalkanes; see R. K. Hill, *J. Org. Chem.*, **22**, 830 (1957).

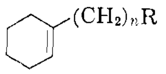
[8] A preliminary account of this work was reported by R. K. Hill and R. T. Conley, *Chemistry & Industry*, 1314 (1956).



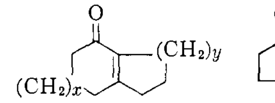
Ia, $x = 1, y = 1$
b, $x = 1, y = 2$
c, $x = 1, y = 3$
d, $x = 2, y = 2$
e, $x = 2, y = 3$



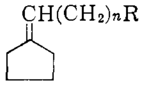
IIa, $x = 1, y = 2$
b, $x = 1, y = 3$
c, $x = 2, y = 2$
d, $x = 2, y = 3$



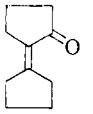
IIIa, $n = 3$, R = CN
b, $n = 3$, R = $CONH_2$
c, $n = 3$, R = CO_2H
d, $n = 4$, R = CN
e, $n = 4$, R = $CONH_2$
f, $n = 4$, R = CO_2H



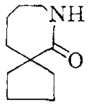
IVa, $x = 1, y = 1$
b, $x = 1, y = 2$
c, $x = 2, y = 1$
d $x = 2, y = 2$



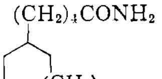
Va, $n = 2$, R = CN
b, $n = 2$, R = CO_2H
c, $n = 3$, R = CN
d, $n = 3$, R = CO_2H
e, $n = 3$, R = $CONH_2$



VI



VII



VIIIa, $n=1$
b, $n=2$

nitric acid oxidation and barium oxide pyrolysis of the diacid yielded Ib. Ic and Ie were prepared by the elegant method of Jacquier and Christol,[9] involving Diels–Alder addition of butadiene to the Mannich bases of cyclopentanone and cyclohexanone. An alternate route to Ie was available in the alkylation of cyclohexanone with 1,5-dibromopentane,[10] and gave a product identical with that from the other method, although the melting points of certain derivatives of the spiroketone and its unsaturated precursor differed appreciably from the values reported. Compound Ic was also prepared by the method of Tinker,[11] but the most economical and least tedious route proved to be *via* barium oxide pyrolysis of the diacid obtained by nitric acid oxidation of the higher homolog Ie. All of the ketones were oximated in high yield using pyridine–ethanol mixtures, and only one pure oxime was formed from each ketone. The configuration with the hydroxyl *trans* to the fully substituted spiro carbon was anticipated for each on steric grounds and substantiated by the products obtained on rearrangement.

Rearrangement of the Oximes.—The rearrangement of the oxime of spiro[4,5]decanone-1 (Ic) was studied most extensively. Phosphorus pentachloride, in benzene at room temperature, cleaved it in nearly quantitative yield to γ-(1-cyclohexenyl)-butyronitrile (IIIa). The cyano group was distinguished by its infrared absorption, and the compound was identified by hydrolysis to the known γ - (1 - cyclohexenyl) - butyramide (IIIb). Using thionyl chloride for the rearrangement, two products were isolated in roughly equal amounts. One was the same unsaturated nitrile, while the other was identified as 1-azaspiro[5,5]undecanone-2 (IIb) by comparison with an authentic sample. *p*-Toluenesulfonyl chloride in pyridine, investigated as a typical alkaline reaction medium, yielded the same mixture of nitrile and lactam.

Since it was clear that a lactam could be obtained from the spirooxime under certain conditions, rearrangement in PPA was tried with anticipation, but to our surprise, the single liquid product, obtained in high yield, proved to be an α,β-unsaturated ketone, as evidenced by its infrared and ultraviolet spectra and the formation of a scarlet 2,4-dinitrophenylhydrazone. Consideration of possible structures led to the conclusion that the product was Δ^9-octalone-1 (IVb); this was quickly confirmed by comparison with a synthetic sample.

The oxime of spiro[4,4]octanone-1 (Ib) behaved in an analogous manner. Thionyl chloride transformed it to a 3:1 mixture of nitrile Va and lactam; the latter was identified as 5-azaspiro[4,5]undecanone-6(IIa) by comparison with a genuine sample. The carbon skeleton of the nitrile was established by hydrolysis to the corresponding acid Vb, which took up one mole of hydrogen upon catalytic reduction to yield γ-cyclopentylbutyric acid, identified by mixed melting point determination of its *p*-bromophenacyl ester with a synthetic sample. The position of unsaturation was determined by ozonolysis of the unsaturated acid and identification of cyclopentanone among the products, thus establishing the structure γ-cyclopentylidene butyronitrile for the cleavage product.[12]

PPA rearranged the oxime in quantitative yield to Δ^8-hydrindenone-4 (IVa), identified by its infrared and ultraviolet spectra and physical constants of its derivatives.

A reasonable mechanism for these reactions, illustrated for the oxime of Ic, is shown in Chart I. As in all Beckmann rearrangements, the reaction is initiated by protonation or esterification of the oxime hydroxyl, weakening the N–O bond sufficiently to allow loss of the hydroxyl, leaving an electron-deficient nitrogen. In the normal rearrangement, loss of the hydroxyl is accompanied by simultaneous migration of the α-carbon *trans* to the oxime hydroxyl, with its pair of electrons, leading to lactam formation. In the two cases under consideration, the lactam formed is the one expected[15] in which the more substituted α-carbon migrates.

The presence of two substituents on an α-carbon permits a second path to compete with bond migration: bond cleavage, in which only the bond-

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(9) R. Jacquier and H. Christol, *Bull. soc. chim. France*, 474 (1953).

(10) M. Mousseron, R. Jacquier and H. Christol, *Compt. rend.*, **239**, 1805 (1954).

(11) J. Tinker, *J. Org. Chem.*, **16**, 1417 (1951).

(12) It is somewhat unexpected to find the double bond *exo* to the cyclopentane ring, rather than in the more stable *endo* position; Turner and Garner[13] have shown that 1-ethylcyclopentene is more stable than ethylidenecyclopentane by 1.3 kcal. The probable explanation is that the reaction conditions are such not to allow equilibrium between the two isomers, and that consequently the more stable product is not necessarily formed. A case is known in the steroid series in which dehydration of a 1-alkylcyclopentanol with $POCl_3$ in pyridine leads to an alkylidene cyclopentane.[14]

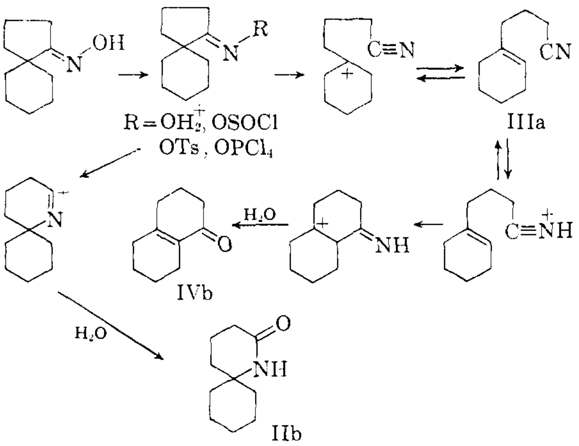
(13) R. B. Turner and R. H. Garner, THIS JOURNAL, **80**, 1424 (1958).

(14) A. Butenandt, J. Schmidt-Thomé and H. Paul, *Ber.*, **72**, 1112 (1939).

(15) H. E. Ungnade and A. D. McLaren, *J. Org. Chem.*, **10**, 29 (1945), and references cited therein.

CHART I

REACTIONS OF SPIRO[4,5]DECANONE-1 OXIME



ing electrons move to satisfy the electron-deficient nitrogen, leaving a stable tertiary carbonium ion. Loss of a proton from this ion forms the unsaturated nitrile IIIa.

In contrast to non-protonating media such as thionyl chloride, phosphorus pentachloride and arylsulfonyl chlorides in pyridine, PPA presents the opportunity for IIIa to react further. Protonation of the cyano group gives an ion which may undergo cyclization with the suitably situated double bond, yielding, after elimination of a proton and hydrolysis of the imine, the octalone IVb. Such cyclizations of unsaturated nitriles were almost unknown, in spite of the fact that the corresponding cyclization of unsaturated acids with PPA or sulfuric acid is a standard preparative method, and the Hoesch reaction represents a similar acid-catalyzed ketone synthesis from a nitrile and an aromatic electron-donor system. Howell and Taylor have since reported[16] the synthesis of a tetrahydrofluorenone from an unsaturated nitrile under Hoesch conditions. The correctness of this proposed step in the mechanism was confirmed by subjecting the unsaturated nitriles IIIa and Va to the action of hot PPA and isolating the same unsaturated ketones formed from the parent oximes.[17] The possibility that the nitrile is first hydrated by PPA to the corresponding amide, which then cyclizes by direct loss of ammonia, is excluded by the finding[7] that PPA converts IIIb directly to the spirolactam IIb.

Rearrangement of the spirocyclohexanone oximes in either thionyl chloride or PPA did not proceed as cleanly as did that of the five-membered ring oximes. Considerable tarry material was formed in every case, and extensive chromatography was necessary to separate and purify the products. The oxime of spiro[4,5]decanone-5 (Id), treated with thionyl chloride, gave a viscous black tar, careful chromatography of which yielded two products in 6–7% yields. The crystalline lactam IIc proved to be identical with the known compound, and the second product, a nitrile, was identified as δ-cyclopentylidenevaleronitrile (Vc) by the following reactions. Alkaline hydrolysis yielded the corresponding acid Vd, which was converted to the crystalline amide Ve and hydrogenated to the saturated amide. This proved to be identical with a sample of δ-cyclopentylvaleramide (VIIIa), synthesized by the Arndt–Eistert sequence from γ-cyclopentylbutyric acid. Ozonolysis of the unsaturated amide Ve and identification of cyclopentanone among the reaction products again showed the *exo* position of the double bond.

Treatment of the oxime with benzenesulfonyl chloride in sodium hydroxide solution hydrolyzed much of the oxime to the parent ketone, but the lactam IIc, identical with that from thionyl chloride rearrangement, was isolated in 30% yield.

PPA gave results surprisingly different from the previous cases. The reaction mixture, a dark viscous oil, was separated by chromatography into three distinct fractions. The first, from its infrared and ultraviolet spectra, was again an α,β-unsaturated ketone. It was not bicyclo[5,3,0]-decene-9-one-1 (IVc), which might have been anticipated by analogy, and a sample of which was synthesized for comparison purposes, but instead 2-cyclopentylidenecyclopentanone (VI), identical in all respects with a sample prepared by alkaline self-condensation of cyclopentanone. Formation of VI requires cyclization of the cyano group with the double bond in the *exo* position, while cyclization with the double bond *endo* would have yielded IVc. It is presumed that although this *endo–exo* pair is interconvertible in PPA, and in spite of the preference for the *endo* position, cyclization occurs faster to a five-membered than to a seven-membered ring.[18]

The second fraction from the chromatograph was a lactam, isolated in 6% yield, which was isomeric, but not identical, with the lactam from thionyl chloride rearrangement. It is assigned the structure VII, and must be formed by rearrangement of a small amount of the isomeric oxime, either present in the starting material or, more likely, produced by acid-catalyzed isomerization during the reaction with PPA. This isomeric oxime, although α,α-disubstituted, does not meet the apparent geometric requirement for the cleavage reaction (*trans-anti*-parallel alignment of the oxime hydroxyl and the bond being cleaved)[19] and consequently undergoes a normal rearrangement.

The third product was a crystalline solid (32%), which displayed infrared absorption characteristic of a primary amide. Isolation of an amide under these conditions is not surprising, since nitriles, anticipated as the initial cleavage products of these oximes, are known to be hydrated to amides in PPA.[20] Empirical analysis showed that this product had two hydrogens more than calculated for an amide produced by hydrolysis of the expected unsaturated nitrile, however, and the com-

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[16] F. H. Howell and D. A. H. Taylor, *J. Chem. Soc.*, 3011 (1957).

[17] The cyclization of Va must, of course, be preceded by migration of the double bond into the *endo* position.

[18] W. S. Johnson, "Organic Reactions," Vol. 11, John Wiley and Sons, Inc., New York, N. Y., 1944, p. 117.

[19] Compare the normal rearrangement of β-benzil monoximes, in which this requirement is not met; J. Meisenheimer and H. Lange, *Ber.*, **57**, 282 (1924).

[20] H. R. Snyder and C. T. Elston, THIS JOURNAL, **76**, 3039 (1954).

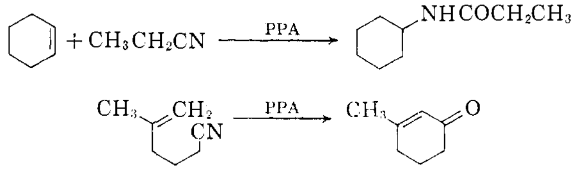
pound gave no tests for unsaturation. It was, indeed, shown to be identical with the synthetic δ-cyclopentylvaleramide (VIIIa). The saturated amide is not formed from the unsaturated nitrile Vc and PPA alone, since in a separate experiment these reacted to yield a mixture of the cyclization product, cyclopentylidenecyclopentanone (VI) and the simple hydrolysis product, δ-cyclopentylidenevaleramide (Ve). Accordingly, either some third compound is required to act as a reducing agent, or the saturated amide is formed directly from the oxime by an alternate, competing process. The reduction of carbonium ions by organic compounds which can serve as hydride donors, *e.g.*, alcohols,[21] formic acid, and hydrocarbons,[22] is a process which could conceivably account for this result, but the identity of the hydride donor, if such is involved, is unknown. Reduction by hydroxylamine, as illustrated in several examples,[23] presents another possibility, but one for which we have been unable to adduce any support. Further work on this problem is in progress.

Formation of the saturated amide became the main reaction when the oxime of spiro[5,5]undecanone-1 (Ie) was heated in PPA, and δ-cyclohexylvaleramide (VIIIb), identical with a synthetic sample, was isolated in over 80% crude yield. Chromatography of the reaction mixture revealed small amounts of two other products, in addition. A lactam, $C_{11}H_{19}NO$, was isolated in 1% yield; which of the two possible structures it possesses was not determined. Finally, about 10% of an α,β-unsaturated ketone was found. It took up one mole of hydrogen on catalytic reduction to form the known *cis*-hexahydrobenzsuberone, and thus appeared to be bicyclo[5,4,0]undecene-10-one-1 (IVd), but since the physical constants did not agree with those recently reported by Ginsburg and Rosenfelder[24] for this compound, an independent synthesis seemed desirable. Accordingly, γ-(1-cyclohexenyl)-butyric acid (IIIc) was homologated by the Arndt–Eistert procedure to δ-(1-cyclohexenyl)-valeramide (IIIe), which was hydrolyzed to the corresponding acid IIIf. PPA cyclization of this acid yielded a ketone identical with the product of Beckmann rearrangement. The compound which Ginsburg and Rosenfelder assigned this structure is most likely a double-bond isomer; the ultraviolet spectrum which they report for the dinitrophenylhydrazone is more in accord with a less substituted α,β-unsaturated ketone.

Reaction of the oxime with thionyl chloride yielded a viscous black tar from which no pure products could be separated. Dehydration of IIIe with phosphorus pentoxide gave the corresponding nitrile IIId, however, which in hot PPA provided the same ketone as did the spiro oxime.

The rearrangement of the oxime of spiro[3,4]-octanone-4 (Ia) in PPA gave a dark tarry mass from which no pure products could be isolated. The proclivity of the cyclobutyl cation to rearrange to systems (cyclopropylcarbinyl and allylcarbinyl)[25] sensitive to hot PPA may account for this.

One other aspect of the behavior of unsaturated nitriles in PPA is of considerable interest. The well-known reaction discovered by Ritter and Minieri[26] (in which an olefin reacts with a nitrile in acid solution to produce an amide) and the acid-catalyzed cyclization of unsaturated nitriles to lactones[27] or imino-ethers[28] represent reasonable and known courses for these molecules to follow; one might inquire why the unsaturated nitriles obtained by cleavage of the oximes in this work did not take these courses in PPA to produce spiro-lactams, lactones or imino-ethers. The difference in behavior was pointed up more strongly by showing that an equimolar mixture of cyclohexene and propionitrile reacted in PPA in a typical Ritter reaction to yield N-propionylcyclohexylamine, while 5-methyl-5-hexene nitrile cyclized by the alternate route in PPA to form 3-methylcyclohexene-2-one. Models indicate that the reason the unsaturated nitriles studied here do not react by the Ritter reaction may be that the chain of methylene groups connecting the cyano function to the double bond may not be long enough to permit the nitrogen of the linear cyano group to approach the intermediate carbonium ion. Studies under way with unsaturated nitriles of varying chain length will help to answer this question.



Should one of the α-substituents on an α-trisubstituted oxime be a hetero atom, especially N or O, it would be anticipated that the intermediate carbonium ion formed by cleavage would gain in stability enough that loss of a proton to form an unsaturated nitrile would become less likely. Consequently, the ion should not react further until hydrolysis, when the C–X bond would be broken. It has been possible to demonstrate this by treating the oxime of spiro[cyclopentane-1,2′-pseudoindoxyl] (IX) with PPA, causing cleavage by the path shown to anthranilamide and cyclopentanone.[29] This novel cleavage reaction has been utilized by Bartlett, Dickel and Taylor

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[21] (a) J. Schmidlin and A. Garcia-Banús, *Ber.*, **45**, 3188 (1912); (b) P. D. Bartlett and J. D. McCollum, This Journal, **78**, 1441 (1956), and references cited therein; (c) "Organic Syntheses," Coll. Vol. 1, 2nd edition, John Wiley and Sons, Inc., New York, N. Y., 1941, p. 548.

[22] P. D. Bartlett, F. E. Condon and A. Schneider, This Journal, **66**, 1531 (1944).

[23] (a) E. Wenkert, B. S. Bernstein and J. H. Udelhofen, *ibid.*, **80**, 4899 (1958); (b) "Organic Syntheses," Coll. Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1955, p. 91.

[24] D. Ginsburg and W. J. Rosenfelder, *Tetrahedron*, **1**, 3 (1957).

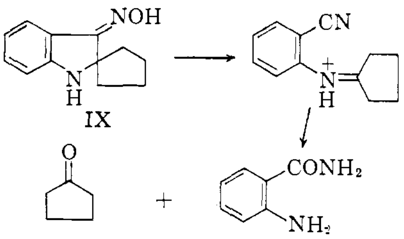
[25] J. D. Roberts and R. H. Mazur, This Journal, **73**, 2509 (1951).

[26] J. J. Ritter and P. P. Minieri, *ibid.*, **70**, 4045 (1948).

[27] N. R. Easton, J. H. Gardner and J. R. Stevens, *ibid.*, **69**, 2941 (1947).

[28] P. N. Craig and I. H. Witt, *ibid.*, **72**, 4925 (1950).

[29] This experiment was performed by R. K. H. while employed at Ciba Pharmaceutical Products, Inc., Summit, N. J., during the summer of 1956. It is a pleasure to thank Dr. Emil Schlittler and his research staff, especially Dr. W. I. Taylor, for permission to publish this work and for their interest and many stimulating discussions.



IX

in their elegant structural investigations of the iboga alkaloids.[30]

Acknowledgments.—Fellowships to R. T. C. from E. I. du Pont de Nemours and Co. and from the Associated Newman Clubs of New York are gratefully acknowledged.

Experimental

Melting points were taken by capillary, and are uncorrected. Polyphosphoric acid was a generous gift from the Victor Chemical Co. Infrared spectra were recorded on a Perkin–Elmer model 21 recording spectrophotometer, and were taken in chloroform or carbon tetrachloride solution unless otherwise noted. Petroleum ether refers to the fraction boiling at 60–70°.

Spiro[5,5]undecanone-1 (Ie).—The addition of butadiene to 2-dimethylaminocyclohexanone[10] gave spiro[5,5]-undecene-2-one-7, b.p. 121–123° (14 mm.), lit. b.p. 122–125° (16 mm.), in 65% yield. The following derivatives were prepared:

(a) **The 2,4-dinitrophenylhydrazone**, recrystallized twice from ethanol, melted at 134–135° (lit.[10] m.p. 107–108°).

Anal. Calcd. for $C_{17}H_{20}N_4O_4$: C, 59.29; H, 5.85; N, 16.27. Found: C, 59.14; H, 5.93; N, 16.56.

(b) **The semicarbazone**, recrystallized from aqueous ethanol, melted at 200–201°.

Anal. Calcd. for $C_{12}H_{19}N_3O$: C, 65.12; H, 8.65; N, 18.99. Found: C, 65.38; H, 8.57; N, 18.94.

(c) **The oxime**, recrystallized twice from aqueous ethanol, melted at 126.5–127°.

Anal. Calcd. for $C_{11}H_{17}NO$: C, 73.70; H, 9.56; N, 7.81. Found: C, 74.00; H, 9.71; N, 7.66.

Hydrogenation of the unsaturated spiroketone over Raney nickel in ethanol gave spiro[5,5]undecanone-1, b.p. 105–106° (9 mm.), lit.[10] b.p. 120° (17 mm.), which solidified to colorless crystals, m.p. 39–40°, after recrystallization from pentane.

The 2,4-dinitrophenylhydrazone, twice recrystallized from ethanol, melted at 135–135.5° (lit.[10] m.p. 123–124°).

Anal. Calcd. for $C_{17}H_{22}N_4O_4$: N, 16.18; Found: N, 16.36.

The oxime, recrystallized twice from aqueous ethanol, melted at 111.5–112°.

Anal. Calcd. for $C_{11}H_{19}NO$: C, 72.88; H, 10.57; N, 7.73. Found: C, 72.56; H, 10.26; N, 7.59.

The saturated spiroketone was also prepared in 30% yield by the alkylation of cyclohexanone with 1,5-dibromopentane and potassium *t*-butoxide,[10] and was identical with the product described above.

Spiro[4,5]decanone-1 (Ic).—Spiro[5,5]undecanone-1 (50 g.), warmed enough to become molten, was added dropwise from an addition funnel to a boiling mixture of concentrated nitric acid (200 ml.) and 2 g. of ammonium vanadate. Nitric acid (100 ml.) was added in portions during the addition to replace that vaporized. When the addition was complete, the mixture was boiled for 15 minutes, then filtered hot through a sintered glass funnel. A viscous oil separated on cooling and solidified on standing. The weight of crude product was 50 g.; a sample for analysis was recrystallized twice from aqueous ethanol, yielding pure γ-(1-carboxycyclohexyl)-butyric acid, m.p. 104–105°.

Anal. Calcd. for $C_{11}H_{18}O_4$: C, 61.66; H, 8.47. Found: C, 61.61; H, 8.44.

The crude diacid was heated with 5 g. of barium oxide for 4–5 hours at 320°, and the distillate worked up in the usual manner. Redistillation of the ketone gave 15.2 g. (33% over-all) of spiro[4,5-]decanone-1, b.p. 101–102° (14 mm.), lit.[10] b.p. 105° (18 mm.). **The oxime**, after several recrystallizations from aqueous ethanol, melted at 93.5–94.5° (lit.[10,11] m.p. 92–93°, 95–96°).

The procedures of Tinker[11] and of Jacquier and Christol[10] gave an identical product,[31] but were more time-consuming.

Beckmann Rearrangements. I. Spiro[4,5]decanone-1 Oxime. (a) **With Phosphorus Pentachloride.**—The oxime of Ic (6.0 g.) was dissolved in 80 ml. of dry benzene, cooled in ice and treated with 8.0 g. of phosphorus pentachloride in small portions. When the exothermic reaction ceased, the flask was stoppered and kept overnight. The solution was washed successively with water, dilute sodium carbonate, and saturated salt solution, then filtered and concentrated. The infrared spectrum of the concentrate showed a strong nitrile band at 4.44 μ and only a short peak at 6.03 μ, indicating less than 5% of lactam. Distillation through a short column gave 5.12 g. (96%) of **γ-(1-cyclohexenyl)-butyronitrile (IIIa)**, b.p. 131–141° (11 mm.). A sample for analysis was chromatographed over alumina in ether and twice redistilled.

Anal. Calcd. for $C_{10}H_{15}N$: C, 80.48; H, 10.13. Found: C, 80.47; H, 10.12.

Hydrolysis.—The nitrile (5.1 g.) was refluxed for 16 hours with a solution of 3.0 g. of potassium hydroxide in 20 ml. of water and 50 ml. of ethanol. The alcohol was then distilled and the residue diluted with ice and water. A crystalline solid (0.93 g.) separated which, after three recrystallizations from ethyl acetate–petroleum ether, melted at 96–97°. It did not depress the melting point (97–98°) of an authentic sample of **γ-(1-cyclohexenyl)-butyramide (IIIb)**.[7]

The filtrate from the separation of the amide smelled distinctly of unreacted nitrile; it was washed with ether, then acidified and extracted with ether. The extracts, after washing with saturated salt solution, drying over sodium sulfate and concentrating, yielded 2.12 g. of **γ-(1-cyclohexenyl)-butyric acid (IIIc)**, b.p. 147–160° (11 mm.). A sample for analysis redistilled at 150–152° (11 mm.), lit.[32] b.p. 122–125° (0.8 mm.).

Anal. Calcd. for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.38; H, 9.32.

(b) **With Thionyl Chloride.**—To a solution of 4.0 g. of the oxime in 40 ml. of dry benzene, cooled in an ice-bath, was slowly added 6.0 ml. of redistilled thionyl chloride, causing an immediate exothermic reaction with gas evolution. The solution was kept at room temperature for 16 hours and evaporated at reduced pressure. The infrared spectrum indicated that roughly equal amounts of nitrile and lactam were present. The mixture was taken up in ether–petroleum ether and seeded with lactam; 1.27 g. (32%) of **1-azaspiro[5,5]undecanone-2** (IIb) separated on standing. The solid melted at 117–118° after sublimation *in vacuo*, undepressed by admixture with an authentic sample.[7] The nitrile was obtained from the filtrate by chromatography over alumina in petroleum ether and elution with ether; its infrared spectrum was identical with that of the nitrile IIIa from phosphorus pentachloride rearrangement.

(c) **With *p*-Toluenesulfonyl Chloride in Pyridine.**—The oxime (1.6 g.) in 15 ml. of dry pyridine was treated with 2.0 g. (5–10% excess) of *p*-toluenesulfonyl chloride in 10 ml. of pyridine, and the solution kept 11 hours at room temperature. After pouring onto ice, acidifying with hydrochloric acid and extracting with chloroform, the extracts were washed with water, dried and concentrated. The infrared spectrum indicated both nitrile (4.47 μ) and lactam (3.15, 3.30, 6.04 μ), again in roughly equal amounts. The lactam IIb (0.55 g., 34%) was obtained by seeding; after recrystallization from petroleum ether and sublimation *in vacuo* it melted at 118–119°, alone or mixed with an authentic sample.

(d) **In PPA.**—The oxime (1.04 g.) was heated with 30 g. of PPA in an oil-bath at 125–130° for 10 minutes with thorough stirring, then poured onto ice and made alkaline with sodium hydroxide solution. The solution was extracted with chloroform and the extracts washed with

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[30] M. F. Bartlett, D. F. Dickel and W. I. Taylor, THIS JOURNAL, **80**, 126 (1958). (b) A similar cleavage of α-amino oximes has been observed recently by H. Fischer, C. A. Grob and E. Renk, *Helv. Chim. Acta*, **42**, 872 (1959).

[31] The authors express their thanks to Charles Bourne for assistance in these preparations.

[32] J. W. Cook and C. A. Lawrence, *J. Chem. Soc.*, 1637 (1935).

water, dried and concentrated, leaving 0.88 g. (94%) of a yellow oil, which was purified by passage of its ether solution through a column of alumina. The product absorbed in the infrared at 5.98 and 6.10 μ and in the ultraviolet at 244 mμ. The 2,4-dinitrophenylhydrazone formed scarlet needles which, after chromatography over alumina in ether, melted at 264.5–265.5° (lit.[33] m.p. 264–266°) undepressed by admixture with the dinitrophenylhydrazone of **Δ^9-octalone-1 (IVb)**. The infrared spectrum of the oil was indistinguishable from that of the authentic ketone.

Δ^9-Octalone-1 (IVb).—(a) 1.0 g. of γ-(1-cyclohexenyl)-butyric acid (IIIc) was stirred into 30 g. of PPA, heated at 120–130° for 10 minutes, and worked up by the procedure used in the Beckmann rearrangements. The infrared spectrum of the crude product indicated a fair amount of lactone (5.73 μ) in addition to octalone. The 2,4-dinitrophenylhydrazone, after chromatography over alumina in ether–chloroform, melted at 263–264°, alone or mixed with the above derivative.

(b) 0.5 g. of γ-(1-cyclohexenyl)-butyronitrile (IIIa) was stirred into 15 g. of PPA, heated at 130° for 10 minutes, and worked up as above. The infrared spectrum of the product was identical with that of the octalone from the other preparations, and the 2,4-dinitrophenylhydrazone, after chromatography in ether, melted at 264.8–265.8°, undepressed by admixture with the derivative from the Beckmann product.

(c) γ-(2-Ketocyclohexyl)-butyric acid[34] (8.6 g.), dissolved in 60 ml. of ethanol, was hydrogenated at 2.5 atm. over Raney nickel. The residue, after filtering the catalyst and removing the alcohol, was stirred into 250 g. of PPA and heated at 130–140° for 15 minutes, then worked up as before. The product (3.0 g.) distilled at 120–122° (11 mm.), lit.[33] b.p. 116–123° (11 mm.): its infrared spectrum was identical with that of a genuine sample.

II. **Spiro[4,4]nonanone-1 Oxime.**[35] (a) **With Thionyl Chloride.**—A solution of 5.0 g. of the oxime of Ib in 50 ml. of dry benzene was cooled to 0° and 10 ml. of redistilled thionyl chloride added dropwise. After standing 18 hours at room temperature, the solution was concentrated under reduced pressure. The residue was diluted with petroleum ether and kept at 0° for 12 hours, whereupon a crystalline solid (1.05 g., 21%) was obtained. After recrystallization from petroleum ether, sublimation *in vacuo* at 100°, and one more recrystallization, it yielded pure **6-azaspiro[4,5]-decanone-7 (IIa)**, m.p. 105–106°, undepressed by admixture with an authentic sample.[7]

The filtrate from the separation of the lactam was evaporated and the residual oil twice chromatographed in ether over alumina to yield 3.37 g. (76%) of colorless γ-**cyclopentylidenebutyronitrile** (Va). A sample was distilled *in vacuo* for analysis.

Anal. Calcd. for $C_9H_{13}N$: C, 79.95; H, 9.69; N, 10.36. Found: C, 79.80; H, 9.67; N, 10.25.

Hydrolysis.—The above nitrile (1.0 g.) was refluxed with a solution of 2.5 g. of sodium hydroxide in 5 ml. of water and 20 ml. of ethanol for 8 hours. The mixture was diluted with an equal volume of water and the alcohol distilled. The remaining alkaline solution was washed with ether, then acidified with dilute hydrochloric acid and extracted with ether. The extracts were dried and concentrated, and the residue distilled *in vacuo*, yielding 1.0 g. of **γ-cyclopentylidenebutyric acid** (Vb). The *p*-bromophenacyl ester was recrystallized from ethanol to yield colorless crystals, m.p. 65–66°.

Anal. Calcd. for $C_{17}H_{19}O_3Br$: C, 58.13; H, 5.45; Br, 22.75; Found: C, 58.20; H, 5.55; Br, 23.0.

γ-Cyclopentylbutyric Acid.—A solution of 0.5 g. of the unsaturated acid Vb in 100 ml. of 2% sodium hydroxide solution was hydrogenated at 4 atm. over Raney nickel. The mixture was filtered, acidified, and extracted with ether. The dried extracts were concentrated and converted directly to the *p*-bromophenacyl ester, which melted at 79.5–81° after two recrystallizations from ethanol. The m.p. was not depressed by mixing with the derivative prepared from an authentic sample of the acid.[36]

Anal. Calcd. for $C_{17}H_{21}O_3Br$: C, 57.80; H, 5.71; Br, 22.62. Found: C, 57.95; H, 5.80; Br, 22.6.

Ozonolysis of γ-Cyclopentylidenebutyric Acid.—A solution of 20 mg. of the unsaturated acid Vb in 10 ml. of glacial acetic acid was ozonized with a stream of oxygen containing 4% ozone. Water (10 ml.) was added and oxygen bubbled through the solution for 10 minutes. The solution was made alkaline with dilute sodium hydroxide and extracted with ether; the extracts were dried, concentrated, and treated with 2,4-dinitrophenylhydrazine reagent, yielding cyclopentanone 2,4-dinitrophenylhydrazone, m.p. 143–144°, undepressed by mixing with an authentic sample.

(b) **In PPA.**—The finely powdered oxime of Ib (2.0 g.) was mixed thoroughly with 30 g. of PPA and heated in an oil-bath. An exothermic reaction began at 100°, and the temperature was maintained at 120–130°, with constant stirring, for 10 minutes. The reaction mixture was worked up as before; infrared analysis of the crude product showed the absence of any functional group other than an α,β-saturated ketone (5.97, 6.10 μ). The product was passed through a short column of alumina in ether, yielding 1.71 g. (98%) of **Δ^8-hydrindenone-4 (IVa)**, λ_{max}(EtOH) 249 mμ (log ε 3.96), lit.[37] λ_{max} 250 mμ (log ε 3.95).

Anal. Calcd. for $C_9H_{12}O$: C, 79.37; H, 8.88. Found: C, 79.25; H, 8.64.

The oxime was recrystallized five times from petroleum ether to yield colorless crystals, m.p. 134.5–136°, lit.[38] m.p. 136°.

The semicarbazone, after recrystallization from aqueous methanol, then from methanol alone, melted at 244–246° dec., lit.[37] m.p. 245° dec.

The deep red **2,4-dinitrophenylhydrazone** melted at 252–252.5°, lit.[37] m.p. 250°, after four recrystallizations from chloroform–methanol.

When the spiroöxime was rearranged in PPA at 100–110°, the infrared spectrum of the crude product showed, in addition to the unsaturated ketone absorption, a strong, sharp peak at 4.3 μ (nitrile). The crude mixture was reheated in PPA at 130°, yielding only the hydrindenone.

Cyclization of the Nitrile.—γ-Cyclopentylidenebutyronitrile (Va, 1.0 g.) was treated with 15 g. of PPA at 125–130° as described above. The product formed had an infrared spectrum identical with that of **Δ^8-hydrindenone-4 (IVa)**, and formed a red 2,4-dinitrophenylhydrazone, m.p. 253–253.5°, which did not depress the m.p. of the derivative from the above oxime rearrangement.

III. **Spiro[4,5]decanone-6 Oxime.**[39,40] (a) **With Thionyl Chloride.**—A solution of 7.0 g. of the oxime of Id in 100 ml. of dry benzene was cooled to 0° and 7.0 ml. of thionyl chloride in 20 ml. of benzene added dropwise with stirring. The solution was kept at room temperature for 24 hours, then concentrated under reduced pressure. Benzene (100 ml.) was added and distilled under reduced pressure to ensure complete removal of thionyl chloride. The residue, a viscous black tar. was taken up in a 1:1 chloroform–ether mixture and chromatographed over 210 g. of alumina, eluting with ether.

δ-Cyclopentylidenevaleronitrile (Vc).—Fractions 1–7 yielded 0.50 g. (7.2%) of a red oil, absorbing in the infrared at 4.3 μ. It was distilled in a micro apparatus, then twice chromatographed in ether. The pure nitrile rapidly decolorized both dilute permanganate and bromine solutions.

Anal. Calcd. for $C_{10}H_{15}N$: C, 80.61; H, 10.06; N, 9.32. Found: C, 80.33; H, 9.96; N, 9.01.

6-Azaspiro[4,6]undecanone-7(IIc).—Fractions 10–31, on evaporation, yielded 0.47 g. (6.7%) of a colorless solid, which melted at 112.5–113.5° after vacuum sublimation and did not depress the m.p. of an authentic sample,[7] m.p. 112.7–113.5°.

δ-Cyclopentylidenevaleric Acid (Vd).—The unsaturated nitrile Vc (0.5 g.) was refluxed for 4 hours with 2.0 g. of potassium hydroxide in 25 ml. of 50% ethanol and worked up in the usual way. The acidic product (0.45 g.) was distilled through a micro column for analysis.

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[33] K. Schenker and V. Prelog, *Helv. Chim. Acta*, **36**, 896 (1953).

[34] J. W. Cook and C. A. Lawrence, *J. Chem. Soc.*, 817 (1937).

[35] D. J. Cram and H. Steinberg, THIS JOURNAL, **76**, 2753 (1954).

[36] J. English, Jr., and J. E. Dayan, *ibid.*, **72**, 4187 (1950).

[37] V. Prelog, K. Schenker and W. Kung, *Helv. Chim. Acta*, **36**, 471 (1953).

[38] W. Hückel and R. Schlüter, *Ber.*, **67**, 2107 (1934).

[39] N. D. Zelinskii and N. V. Elagina, *Compt. rend. acad. sci. U.R.S.S.*, **49**, 568 (1945); *C. A.*, **40**, 6058 (1946).

[40] W. Hückel, R. Daneel, A. Schwartz and A. Gercke, *Ann.*, **474**, 121 (1929).

Anal. Calcd. for $C_{10}H_{16}O_2$: C, 72.15; H, 9.53. Found: C, 72.13; H, 9.52.

δ-Cyclopentylidenevaleramide (Ve).—The acid Vd (0.5 g.) was refluxed with oxalyl chloride for 45 minutes, and the cooled mixture added dropwise to cold concentrated ammonium hydroxide. The mixture was diluted with water and extracted with chloroform. The residue, after evaporation of the dried extracts, was recrystallized from ethyl acetate–petroleum ether, then from dilute ethanol, to yield colorless plates, m.p. 100–101°.

Anal. Calcd. for $C_{10}H_{17}NO$: C, 71.81; H, 10.25; N, 8.38. Found: C, 71.47; H, 10,01; N, 8.15.

Ozonolysis.—The amide Ve was ozonized by the procedure described above, yielding cyclopentanone 2,4-dinitrophenylhydrazone, m.p. 141.5–142°, not depressed by mixing with a genuine sample.

Hydrogenation.—The unsaturated amide Ve (25 mg.) was hydrogenated at 4 atm. in ethanol over Raney nickel. Evaporation of the filtered solution, and recrystallization of the product from ethyl acetate–petroleum ether gave **δ-cyclopentylvaleramide** (VIIIa), m.p. 135.5–137° (lit.[41] m.p. 135–136°), undepressed by admixture with an authentic sample.

(b) **With Benzenesulfonyl Chloride and Alkali.**—A mixture of 1.0 g. of the oxime of Id, 1.1 g. of benzenesulfonyl chloride, 0.25 g. of sodium hydroxide, 20 ml. of acetone and 5 ml. of water was refluxed on the steam bath for 4 hours. Water (50 ml.) was added, the acetone removed at reduced pressure, and the aqueous residue thoroughly extracted with ether. After drying and concentrating the extracts, there remained 0.9 g. of a viscous yellow oil, whose infrared spectrum indicated the presence of a lactam and saturated ketone. Crystallization of the mixture from 10 ml. of petroleum ether yielded 0.32 g. of solid which, after recrystallization from petroleum ether and two sublimations *in vacuo*, melted at 112.5–113.5°. It did not depress the melting point of **6-azaspiro[4,6]undecanone-7** (IIc).

Evaporation of the solvent from the filtrate after separation of the lactam yielded 0.56 g. of liquid which was directly converted to its oxime, m.p. 65–66°, not depressed by admixture with the starting material.

(c) **In PPA.**—The finely powdered oxime of Id (9.5 g.) was stirred into 120 g. of PPA and slowly heated, with constant stirring. An exothermic reaction began at 100°. After 10 minutes at 120–125°, the mixture was worked up as described above, to yield 9.0 g. of red viscous oil. This was separated into three fractions by chromatography over 310 g. of alumina and elution with chloroform.

2-Cyclopentylidenecyclopentanone (VI).—Fractions 1–17 yielded 4.52 g. (56%) of a light oil absorbing in the infrared at 5.88 and 6.13 μ, and in the ultraviolet at 256 mμ (log ε 3.94).

The oxime, after repeated recrystallization from ethanol, melted at 122–123° (lit.[42] m.p. 123–124°), not depressed by admixture with an authentic sample.

The deep red **2,4-dinitrophenylhydrazone** was recrystallized five times from chloroform–methanol, when it melted at 237° dec. (lit.[43] m.p. 229–230°), not depressed by admixture with an authentic sample.

7-Azaspiro[4,6]undecanone-6 (VII).—Fractions 24–32 yielded 0.59 g. (6%) of a colorless solid, with infrared absorption at 3.1, 3.3 and 6.0 μ. After two recrystallizations from petroleum ether, followed by vacuum sublimation, it melted at 143–144.5°. Mixed with the lactam IIc, the melting point was depressed to 92–105°.

Anal. Calcd. for $C_{10}H_{17}NO$: C, 71.81; H, 10.25; N, 8.38. Found: C, 71.76; H, 10.17; N, 8.00.

δ-Cyclopentylvaleramide (VIIIa).—Fractions 33–74 gave 3.20 g. (32%) of colorless solid which was sublimed *in vacuo* at 110°, then recrystallized three times from ethyl acetate–petroleum ether, when it melted at 136.5–137.5°. The infrared spectrum, with amide peaks at 2.82, 2.92, 5.95 μ, was identical with that of synthetic VIIIa. A mixture of the two samples showed no m.p. depression.

Cyclization of Nitrile Va.—The unsaturated nitrile Va (0.3 g.) was stirred into 3 g. of PPA, heated at 120–130° for 15 minutes, and worked up in the usual way. Chromatography of the crude mixture over alumina in chloroform gave two products: (1) 2-cyclopentylidenecyclopentanone (VI), identified by its infrared and ultraviolet spectra, and by mixed m.p. determination of the dinitrophenylhydrazone with the sample described above and (2) δ-cyclopentylidenevaleramide (Ve), m.p. 100.5–101°, undepressed by mixture with the sample described previously.

IV. Spiro[5,5]undecanone-1-oxime. (a) **In PPA.**—The finely powdered oxime of Ie (5.0 g.) was heated with 55 g. of PPA at 120–130° for 10 minutes with constant stirring and worked up as described previously. The infrared spectrum of the crude product indicated the presence of amide and unsaturated ketone. The mixture was separated by chromatography over alumina into the following compounds.

(1) **Bicyclo[5,4,0]undec-10-en-5-one** (IVd).—Ether eluted a light yellow oil (0.45 g., 10%) which absorbed in the infrared at 6.08 and 6.2 μ in the ultraviolet at 244 mμ (log ε 3.96). A pure sample was regenerated from the dinitrophenylhydrazone with pyruvic acid and chromatographed over alumina in ether.

Anal. Calcd. for $C_{11}H_{16}O$: C, 80.44; H, 9.82. Found: C, 80.15; H, 9.61.

The 2,4-dinitrophenylhydrazone, after three recrystallizations from chloroform–methanol, melted at 203–205° dec., lit.[24] m.p. 170–171°. It absorbed in the ultraviolet at 387 mμ (ε 16,000), lit.[24] λ_{max} 369 mμ (ε 24,100).

Anal. Calcd. for $C_{17}H_{20}N_4O_4$: C, 59.29; H, 5.85; N, 16.27. Found: C, 59.25; H, 5.93; N, 16.25.

Hydrogenation.—The unsaturated ketone IVd (0.5 g.) was hydrogenated over Adams catalyst at 4 atm. pressure in glacial acetic acid. After 48 hours, the catalyst was filtered and the filtrate warmed for an hour with a solution of 20 mg. of chromium trioxide in 10 ml. of 50% acetic acid. The reaction mixture was poured onto ice, treated with sodium hydrosulfite to remove excess oxidant, neutralized with sodium carbonate and extracted with chloroform. The ketone left after evaporation of the dried extracts was converted directly to its 2,4-dinitrophenylhydrazone, m.p. 145–146.5°, not depressed by admixture with an authentic sample[44] of *cis*-α-hexahydrobenzsuberone 2,4-dinitrophenylhydrazone, lit. m.p. 146–147°.

Synthesis of IVd.—(a) δ-(1-Cyclohexenyl)-valeric acid (IIIf, 0.6 g.) was heated with 8 g. of PPA at 70–80° for one hour with stirring. The reaction mixture was poured into 100 ml. of crushed ice, neutralized with sodium hydroxide and extracted continuously with chloroform. Evaporation of the dried extracts, followed by chromatography of the residue over alumina in ether, yielded 0.2 g. of **bicyclo[5,4,0]undec-10-en-5-one (IVd)**, λ_{max} 244 mμ (log ε 3.96). The infrared spectrum was indistinguishable from that of the ketone from Beckmann rearrangement. The 2,4-dinitrophenylhydrazone, recrystallized twice from chloroform–methanol, melted at 202–203.5° dec. alone or mixed with the derivative from the Beckmann ketone.

(b) 1.0 g. of δ-(1-cyclohexenyl)-valeronitrile (IIId) was heated with 20 g. of PPA at 120–125° for 15 minutes and worked up as described above. The crude product was converted to its 2,4-dinitrophenylhydrazone which, after two recrystallizations from chloroform–methanol, melted at 202–203.5°; the melting point was not depressed by mixing with the above derivative.

(2) **Unidentified Lactam.**—Chloroform–ether (1:3) eluted 0.05 g. (1%) of colorless solid with infrared absorption (2.92, 6.07 μ) characteristic of a lactam. Rechromatography in chloroform–ether followed by vacuum sublimation gave 26 mg. of colorless crystals, m.p. 137–138°.

Anal. Calcd. for $C_{11}H_{19}NO$: C, 72.88; H, 10.57; N, 7.73. Found: C, 72.69; H, 10.26; N, 7.70.

(3) **δ-Cyclohexylvaleramide** (VIIIb).—Elution with 3:1 chloroform–ether gave 4.14 g. (83%) of impure solid, which was crystallized five times from ethyl acetate–petroleum ether to yield colorless plates, m.p. 122–122.5° (lit.[45] m.p. 122–123°), undepressed by admixture with an authentic sample.

δ-(1-Cyclohexenyl)-valeramide (IIIe).—γ-(1-Cyclohexenyl)-butyric acid (IIIc) (11.3 g.) was treated in the cold with 15 g. of oxalyl chloride, slowly warmed to room tem-

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[41] G. H. Coleman, J. E. Callen and C. A. Dornfeld, THIS JOURNAL, **68**, 1101 (1946).

[42] O. Wallach, *Ber.*, **29**, 2955 (1896).

[43] O. B. Edgar and D. H. Johnson, *J. Chem. Soc.*, 3925 (1958).

[44] C. D. Gutsche and H. H. Peter, THIS JOURNAL, **77**, 5971 (1955).

[45] M. M. Katsnel'son and B. M. Dubinin, *Compt. rend. acad. sci. U.R.S.S.*, **4**, 405 (1936); *C. A.*, **31**, 3449 (1937).

perature, then refluxed on the steam-bath for two hours. The excess oxalyl chloride was evaporated at reduced pressure, the residue taken up in ether, and added to an ice-cold ethereal solution of diazomethane from 17 g. of nitrosomethylurea. The solution was allowed to stand for three hours, concentrated, and the solid residue refluxed for three hours with a solution of 100 ml. of dioxane, 40 ml. of concentrated ammonium hydroxide and 10 ml. of 10% aqueous silver nitrate solution. After standing overnight, the solution was decolorized, warmed, and diluted with water to the cloud point. After standing two days in the refrigerator, the crystals which had separated were collected and recrystallized from ethyl acetate–petroleum ether, yielding 7.0 g. of **δ-(1-cyclohexenyl)-valeramide**, m.p. 106–107°.

Anal. Calcd. for $C_{11}H_{19}NO$: C, 72.88; H, 10.57; N, 7.73. Found: C, 72.53; H, 10.60; N, 7.90.

δ-(1-Cyclohexenyl)-valeric Acid (IIIf).—A solution of 1.5 g. of IIIe and 4.0 g. of potassium hydroxide in aqueous methanol was refluxed for 24 hours. The methanol was evaporated and the residue diluted with water, then washed with chloroform and acidified with dilute hydrochloric acid. Extraction with chloroform gave, after drying and concentrating the extracts, 1.3 g. of the acid, b.p. 115° (0.02 mm.).

Anal. Calcd. for $C_{11}H_{18}O_2$: C, 72.49; H, 9.96. Found: C, 72.41; H, 9.96.

δ-(1-Cyclohexenyl)-valeronitrile (IIId).—An intimate mixture of 2.5 g. of pulverized amide IIIe and 5.0 g. of phosphorus pentoxide was distilled *in vacuo*. The distillate was taken up in 25 ml. of ether, washed with 25 ml. of 5% sodium carbonate solution, then dried and evaporated. Vacuum distillation of the residue yielded 1.89 g. of nitrile, which was further purified by chromatography over alumina in ether.

Anal. Calcd. for $C_{11}H_{17}N$: C, 80.92; H, 10.50; N, 8.58. Found: C, 80.63; H, 10.25; N, 8.31.

V. Spiro[3,4]octanone-1 Oxime.[46]—The oxime of Ia (1.5 g.) was heated in 15 g. of PPA at 125–130° for 10 minutes and worked up as described before. The crude product was a black tarry mass from which no pure compounds could be isolated.

3-Methylcyclohex-2-enone.—5-Methyl-5-hexenenitrile[47] (2.0 g.) was heated in 70 g. of PPA at 130–135° for 15 minutes and worked up as before. The crude product contained unreacted nitrile in addition to unsaturated ketone, as evidenced by the infrared spectrum, and was converted directly to the 2,4-dinitrophenylhydrazone. After two recrystallizations from chloroform–methanol, this yielded scarlet plates, m.p. 181–182° (lit.[48] m.p. 172.5–173°), with no m.p. depression on admixture with an authentic sample.[49]

N-Propionylcyclohexylamine.—A mixture of 4.2 g. of cyclohexene and 2.8 g. of propionitrile was stirred into 168 g. of PPA, slowly heated to 130°, and maintained at that temperature for 10 minutes. The crude reaction mixture, which showed no ketone bands in the infrared, yielded 3.0 g. of solid, which was recrystallized from ethanol to colorless needles, m.p. 90–91.5°. Sublimation at 90° *in vacuo*, and recrystallization from benzene–petroleum ether, raised the m.p. to 92–92.5° (lit.[50] m.p. 88°), undepressed by admixture with an authentic sample.

Rearrangement of Spiro[cyclopentane-1,2-pseudoindoxyl] Oxime.—The oxime[51] (0.68 g.) was stirred into 20 g. of PPA and kept at 110–115° for 10 minutes. The mixture was poured onto ice and stirred until it became homogeneous, filtered, saturated with salt and extracted with methylene chloride. The extracts were washed with saturated salt solution, dried over sodium sulfate, and evaporated through a short column. The residue was treated with 2,4-dinitrophenylhydrazine reagent to yield 0.53 g. (59%) of **cyclopentanone 2,4-dinitrophenylhydrazone**, m.p. 126–129°. Recrystallization from ethanol raised the m.p. to 139–140°, undepressed by admixture with an authentic sample.

The aqueous solution remaining from the extraction was made strongly alkaline with sodium hydroxide solution and extracted with methylene chloride. The extracts were washed with saturated salt solution, dried and concentrated, yielding 0.29 g. (63%) of pale yellow **anthranilamide**, m.p. 104–105°. Two recrystallizations from benzene afforded colorless leaflets, m.p. 107.5–108.5°, undepressed by admixture with an authentic sample.

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[46] E. Vogel, *Ber.*, **85**, 25 (1952).

[47] Obtained through the courtesy of M. J. Hogsed, E. I. du Pont de Nemours and Co., to whom the authors express their thanks.

[48] C. S. Marvel and C. L. Levesque, THIS JOURNAL, **60**, 280 (1938).

[49] The ketone was prepared by the method of L. I. Smith and G. F. Rouault, *ibid.*, **63**, 631 (1943).

[50] W. Scharvin, *Ber.*, **30**, 2862 (1897).

[51] R. J. S. Beer, L. McGrath and A. Robertson, *J. Chem. Soc.*, 2118 (1950).

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[CONTRIBUTION FROM THE MCPHERSON CHEMICAL LABORATORY OF THE OHIO STATE UNIVERSITY]

Condensed Cyclobutane Aromatic Compounds. IX. Benzocyclobutenol and Benzocyclobutenone

BY M. P. CAVA AND K. MUTH

RECEIVED JUNE 12, 1959

Starting from 1-bromobenzocyclobutene, syntheses of benzocyclobutenol and benzocyclobutenone have been achieved. Cleavage of the four-membered ring of both the alcohol and the ketone occurs readily under basic conditions.

Probably the most interesting simple derivatives of benzocyclobutene which have not yet been described are the alcohol and the ketone, benzocyclobutenol (I) and benzocyclobutenone (II). The synthesis of both of these compounds is now reported.

The bromine atom of 1-bromobenzocyclobutene (III)[1,2] was replaced by hydroxyl in an indirect manner under very mild conditions. The reaction of III with silver trifluoroacetate proceeded readily in benzene solution at room temperature to give, in 87% yield, benzocyclobutenyl trifluoroacetate (IV) as a pleasant smelling oil. The hydrolysis of the trifluoroacetate was carried out either by shaking at room temperature with aqueous sodium carbonate, or by ester exchange in refluxing methanol in the presence of an acidic ion exchange catalyst. Benzocyclobutenol (I) was obtained in good yield by either procedure as beautiful colorless needles, m.p. 58°. Preliminary experiments indicate that I is not particularly sensitive to dilute mineral acids, but is surprisingly unstable in the presence of sodium hydroxide. After standing with 0.25 *N* sodium hydroxide for one hour at room temperature the alcohol I was converted in 72% yield to *o*-tolualdehyde. The driving force for this unusual cleavage, which proceeds almost certainly *via* an alkoxide intermediate (Ia), is the

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[1] M. P. Cava and D. R. Napier, THIS JOURNAL, **80**, 2255 (1958).

[2] L. Horner, W. Kirmse and K. Muth, *Chem. Ber.*, **91**, 430 (1958).