the excess solvent, 25 g. (88%) of tetraphenylethylene was isolated.

Alcoholic Potassium Hydroxide.—To a warm solution of 10 g. of potassium hydroxide in 90 g. of ethyl alcohol was added 2 g. of benzpinacolyl alcohol (0.006 mole) and refluxed for four hours. The reaction mixture was poured into water and extracted with benzene. From the benzene extraction, 1.30 g. (93%) of triphenylmethane and a small amount of benzaldehyde were isolated.

Diazomethane in Ether.—Run No. 1: to an ethereal solution of diazomethane prepared by adding 20 g. of powdered nitrosomethyl urea in small portions to 200 ml. of ether and 60 ml. of 40% potassium hydroxide, was added 17 g. of benzpinacolyl alcohol (0.048 mole) dissolved in 500 ml. of ether at a temperature of 0–5°. The reaction mixture was then heated for forty-three hours. After distilling the excess solvent, 16 g. (94%) of benzpinacolyl alcohol, and traces of triphenylmethane, were obtained. Run No. 2: 10 g. (0.028 mole) and 1 g. of aluminum isopropoxide dissolved in 200 ml. of ethyl ether were added to an ethereal solution of diazomethane prepared as indicated in Run No. 1. The temperature was maintained at 0–5° during addition, and the reaction mixture was then refluxed for eighteen hours. The excess solvent was distilled giving 9.2 g. (92%) of benzpinacolyl alcohol. **Glacial Acetic Acid.**—25 g. (0.071 mole) was heated in 200 ml. of glacial acetic acid at 60–67° for one hour. After distillation of the excess acetic acid, 24.6 g. (94.4%) of benzpinacolyl alcohol was recovered. **Lead Acetate and Acetic Acid.**—5 g. (0.014 mole) was heated with 1 g. of lead acetate in 300 ml. of glacial acetic acid for two hours. From the precipitate formed when the reaction mixture was poured into water, 4.2 g. (84%) of benzpinacolyl alcohol and 0.1 g. (2.5%) of tetraphenylethylene were obtained. **Acetic Anhydride.**—20 g. (0.056 mole) was refluxed with 300 ml. of acetic anhydride for eight hours. After distillation of the excess acetic acid, 19.4 g. (97%) of benzpinacolyl alcohol was recovered. **Metallic Sodium in Benzene.**—To 2 g. (0.006 mole) dissolved in 300 ml. of benzene, 0.3 g. of sodium (0.013 gram atom) was added and refluxed for sixteen hours. The reaction mixture was separated from the unreacted sodium, and 0.61 g. of ethyl bromide was added and refluxed for three hours. The excess solvent was distilled off and 1.3 g. of triphenylmethane (94%) and a trace of benzaldehyde were found.

Summary

1. Oxidation of benzpinacolyl alcohol with chromic anhydride gives 61% benzopinacolone, 22% triphenylcarbinol, 7% tetraphenylethylene, and 6% benzaldehyde. Permanganate in acetic acid gave 54% triphenylcarbinol and 57% benzaldehyde. Permanganate in neutral solution or selenium dioxide did not oxidize the alcohol.

2. Lead tetraacetate gave 70% triphenylcarbinol and 4% tetraphenylethylene at 50° and 51% tetraphenylethylene, 33% triphenylcarbinol and 35% benzaldehyde at 120°. The lower yield of cleavage at elevated temperatures argues against a free radical intermediate as does the absence of triphenylmethyl peroxide when the reaction is carried out in the presence of air.

3. Attempts to prepare ethers of benzpinacolyl alcohol have been unsuccessful.

NEWARK, DELAWARE RECEIVED DECEMBER 2, 1949

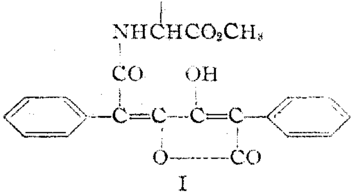
[CONTRIBUTION FROM THE NOYES CHEMICAL LABORATORY, UNIVERSITY OF ILLINOIS]

The Structures and Syntheses of Rhizocarpic Acid and Epanorin[1]

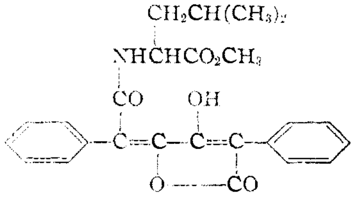
BY ROBERT L. FRANK, S. MARK COHEN AND JAMES N. COKER

Rhizocarpic acid is a yellow pigment isolated in 1844 by Knop[2] from a number of lichens and obtained by Zopf[3] in 1895 from the lichen *Rhizocarpon geographicum*. Epanorin is a similar pigment, first found by Zopf in the lichen *Epanora lecanora*.[4] These are the only known nitrogen-containing lichen pigments.

In this paper are described the structure elucidations, confirmed by synthesis, of these two pigments. Rhizocarpic acid (I) is the amide of pulvinic acid with the methyl ester of L-phenylalanine; epanorin (II) is the corresponding derivative of L-leucine.[5]



I



II

Zopf[3,6] reported a molecular formula of $C_{26}H_{20}O_6$ for rhizocarpic acid; Hesse[7] favored the formula $C_{28}H_{22}O_7$. Neither of these authors, however, recognized the presence of nitrogen in rhizocarpic acid, an understandable oversight since no lichen pigments were then known to contain this element.

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[1] This is the third communication on the chemistry of fungi and lichens. For the first two see THIS JOURNAL, **72**, 1824, 1827 (1950).

[2] Knop, *Ann.*, **49**, 122 (1844).

[3] Zopf, *ibid.*, **284**, 107 (1895).

[4] Zopf, *ibid.*, **313**, 330 (1900).

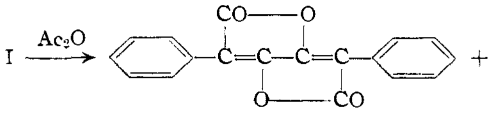
[5] The pulvinic acid derivatives represented in this paper are formulated in the enolic form in accord with previously published structures (see Karrer, Gehrckens and Heuss, *Helv. Chim. Acta*, **9**, 446 (1926)). It is understood that they may actually have the keto form; infrared absorption spectra indicate this may be the case (see reference 12).

[6] Zopf, *Ann.*, **338**, 35 (1905).

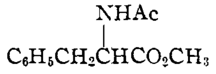
[7] (a) Hesse, *Ber.*, **31**, 663 (1898); (b) *J. prakt. Chem.*, [2] **58**, 465 (1898); (c) *ibid.*, **76**, 1 (1907).

Salkowski[8] established the optical activity of rhizocarpic acid in 1901.

An important contribution to the structure was made by Zopf in his early experiments,[3] in which he discovered that rhizocarpic acid is cleaved by hot acetic anhydride to yield the known pulvinic acid lactone (III),[9] along with a colorless solid



III



$$\overset{\text{NHAc}}{C_6H_5CH_2\overset{|}{C}HCO_2CH_3}$$

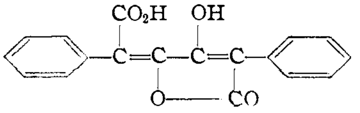
IV

melting at 88°. Hesse[10] subsequently obtained oxalic and phenylacetic acids by barium hydroxide degradation of rhizocarpic acid, but their formation can be attributed to cleavage of the pulvinic acid portion of the molecule.[9]

Saponification of the pigment by means of potassium carbonate or bicarbonate[7b] gave an acid, m. p. 92°, which Hesse called norrhizocarpic acid. This formed an ethyl ester, m. p. 171°.[7c] Hesse considered norrhizocarpic acid to be a dicarboxylic acid, rhizocarpic acid its monoethyl ester, and the ester of m. p. 171° its diethyl ester, since rhizocarpic acid was converted to the compound melting at 171° by heating with ethanolic hydrogen chloride.

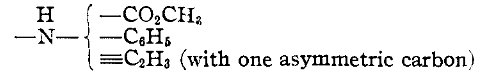
The correct molecular formula, $C_{28}H_{23}O_6N$, for rhizocarpic acid was published in 1944 by Jones, Keane and Nolan.[11] These workers also reported the alkaline cleavage of the pigment to yield methanol, oxalic acid, phenylacetic acid and a colorless fragment of composition $C_{17}H_{17}O_3N$.

The above facts indicate that rhizocarpic acid is a derivative (amide or ester) of pulvinic acid (V). Subtracting the elements of the pulvinyl



V

group from the complete molecular formula ($C_{28}H_{23}O_6N$–$C_{18}H_{11}O_4$) leaves the fragment —$C_{10}H_{12}O_2N$. The fragment should contain a carbomethoxyl group, and this fact suggests by elimination that the fragment is attached to the pulvinyl group through the nitrogen atom. This part of the molecule should also account for the optical activity of the pigment, and further, the low hydrogen content indicates the presence of a phenyl group. Therefore —$C_{10}H_{12}O_2N$ may be represented by



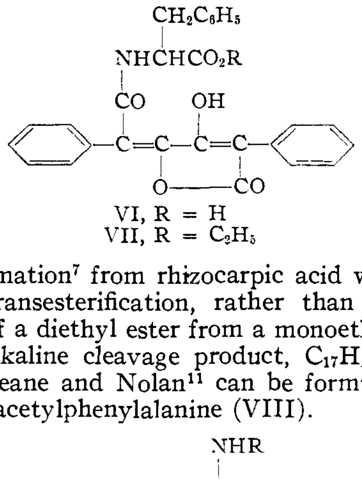
$$\overset{\text{H}}{\text{—N—}}\begin{cases} —CO_2CH_3 \\ —C_6H_5 \\ \equiv C_2H_3 \text{ (with one asymmetric carbon)} \end{cases}$$

or its equivalent. This formulation allows only a few structural choices. One of these is the methyl ester of the phenylalanyl group, an attractive possibility because of the natural occurrence of L-phenylalanine.

The methyl ester of L-phenylalanine was therefore prepared and warmed with a chloroform solution of pulvinic acid lactone (V)[12] to give a yellow crystalline product (I) in 75% yield. This proved to be identical with rhizocarpic acid in m. p. and optical rotation, and in the m. p.'s of the saponified product (norrhizocarpic acid), m. p. 92°, and the transesterification product with ethanol, m. p. 171°. It also yielded pulvinic acid lactone (III) when heated with acetic anhydride.

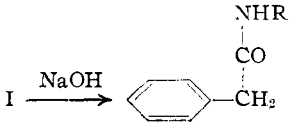
A sample of natural rhizocarpic acid, generously sent us by Dr. John Keane of University College, Dublin, gave no depression in m. p. when mixed with the synthetic pigment, and the infrared absorption spectra of the two samples were identical (Fig. 1).

Considering the correct formula I, it is now possible to assign structures to the various degradation products of rhizocarpic acid. The material of m. p. 88° reported by Zopf[3] is probably the methyl ester of L-acetylphenylalanine (IV). Norrhizocarpic acid is Structure VI; the ethyl ester, m. p. 171°, is Structure VII. Hesse's ethyl ester formation[7] from rhizocarpic acid was actually a transesterification, rather than the formation of a diethyl ester from a monoethyl ester.



VI, R = H
VII, R = C_2H_5

The alkaline cleavage product, $C_{17}H_{17}O_3N$, of Jones, Keane and Nolan[11] can be formulated as L-phenylacetylphenylalanine (VIII).



VIII, R = —$CH(CH_2C_6H_5)CO_2H$

Hesse[7c,13] reported another derivative of rhizocarpic acid, rhizocarpinic acid, m. p. 170°, which he believed occurred in *Rhizocarpon geographicum*. Zopf[14] claimed this was an impure sample of rhizocarpic acid. In light of present knowledge Hesse's rhizocarpinic acid may be the ethyl ester

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[8] Salkowski, *Ann.*, **319**, 391 (1901); Zopf, *ibid.*, **321**, 37 (1902).

[9] Spiegel, *ibid.*, **219**, 1 (1883); Volhard, *ibid.*, **282**, 21 (1894).

[10] Hesse, *J. prakt. Chem.*, **73**, 113 (1906).

[11] Jones, Keane and Nolan, *Nature*, **154**, 580 (1944).

[12] Frank, Clark and Coker, THIS JOURNAL, **72**, 1824 (1950).

[13] Hesse, *Ber.*, **30**, 357 (1897).

[14] Zopf, *Ann.*, **346**, 82 (1906).

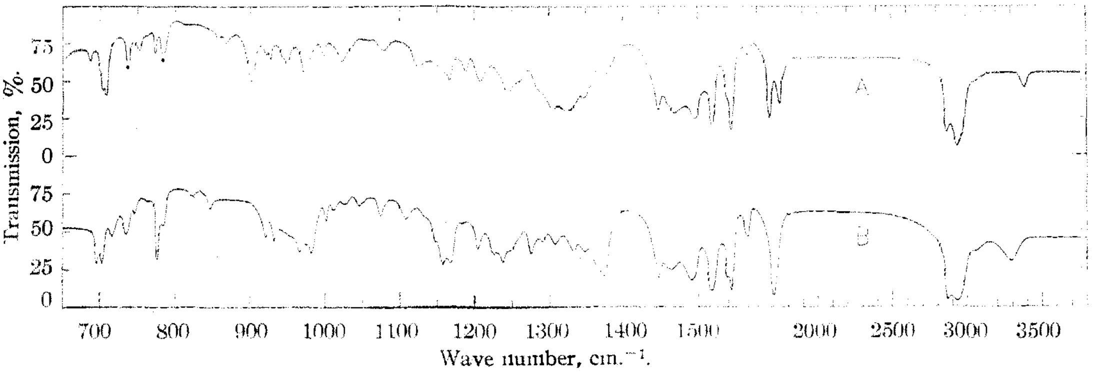

Fig. 1.—Infrared absorption spectra: curves A and B represent crystalline L-rhizocarpic acid and L-epanorin, respectively.

(VII) of norrhizocarpic acid, and may have been formed from rhizocarpic acid during its isolation from the lichen, or it may indeed be present in the lichen.

Epanorin was isolated from *Lecanora epanora* in very small amount by Zopf,[4] and he recorded only its m. p. Jones, Keane and Nolan[11] reported a molecular formula of $C_{25}H_{25}O_6N$, the presence of one methoxyl group, and alkaline degradation to a substance of composition $C_{14}H_{19}O_3N$. In 1946 Keane and his students[15] obtained pulvinic acid lactone (III) and an amine hydrochloride, $C_6H_{13}O_2N \cdot HCl$, by acid cleavage of epanorin.

By analogy with the chemistry of rhizocarpic acid, epanorin might be expected to be the pulvinic acid amide of the methyl ester of leucine or isoleucine. Since L-leucine is more widely distributed in nature than L-isoleucine,[16] its methyl ester was treated with pulvinic acid lactone[12] to form Compound II in 47% yield. This melted at 134–135° and the m. p. was not depressed on mixture with Dr. Keane's natural epanorin, m. p. 134.5–135.5°. Infrared absorption spectra of the two samples were identical (Fig. 1).

It is now possible to formulate the compound $C_{14}H_{19}O_3N$ of Jones, Keane and Nolan[11] as L-phenylacetylleucine (corresponding to VIII in which R equals $—CH(CH_2CH(CH_3)_2)CO_2H$).

We have also prepared the racemic forms of rhizocarpic acid (I), ethyl norrhizocarpate (VII) and epanorin (II). These are remarkable in that they show unusually large variances from m. p.'s of the active forms. DL-Rhizocarpic acid melts 33° *lower* than L-rhizocarpic acid, ethyl DL-norrhizocarpate melts 27° lower than its active form, and DL-epanorin melts 34° *higher* than L-epanorin.

Acknowledgment.—We are pleased to express our gratitude to Dr. John Keane of University College, Dublin, Ireland, for samples of natural rhizocarpic acid and epanorin, to Dr. George A. Llano of the Smithsonian Institution, Washington, D. C., for helpful suggestions and lichen samples, and to Mrs. Volney H. Jones of the University of Michigan Herbarium for lichen samples.

Experimental

All m. p.s are corrected.

***l*-Rhizocarpic Acid** (I).—Two grams (0.012 mole) of L-phenylalanine was suspended in 100 ml. of methanol. Dry hydrogen chloride was passed in for two hours, and the solution was refluxed during this time. The excess methanol was then evaporated under reduced pressure, leaving the white crystalline methyl ester hydrochloride. This was dissolved in 10 ml. of water, the solution cooled to 5°, and 50 ml. of ether was added, followed by the slow addition of 25 ml. of 35% aqueous sodium hydroxide. Immediate extraction with four 50-ml. portions of ether, drying of the extracts over potassium carbonate and evaporation of the ether yielded 1.3 g. of the oily yellow phenylalanine ester. This was dissolved in 78 ml. of chloroform, 1.3 g. (0.0045 mole) of pulvinic acid lactone[12] was added, and the solution refluxed for one hour. Evaporation of the chloroform on a steam cone yielded a brown oil which solidified to yellow crystals. A single recrystallization from methanol gave needles of L-rhizocarpic acid, 1.6 g. (75%), m. p. 175–177°. Further recrystallization from methanol raised the m. p. to 177–178°, $[\alpha]^{20}D$ +110.4 ± 2.1° (1.22 g. per 100 ml. of chloroform solution). *Anal.*[17] Calcd. for $C_{28}H_{23}O_6N$: C, 71.66; H, 4.90; N, 2.99. Found: C, 71.62; H, 4.99; N, 2.99.

A mixture of this compound with natural rhizocarpic acid, m. p. 177–177.5°, melted at 177–178°.

We were not successful in preparing the acetyl derivative of rhizocarpic acid reported by Hesse.[7b]

The infrared absorption spectrum of L-rhizocarpic acid in chloroform solution was essentially the same as that of the crystalline solid (Fig. 1).

L-Norrhizocarpic Acid (VI).—Two-tenths of a gram (0.0005 mole) of L-rhizocarpic acid was suspended in 20 ml. of 10% aqueous potassium carbonate and the mixture refluxed for one-half hour. The resulting yellow solution was filtered hot, cooled to 5°, and acidified with concentrated hydrochloric acid. The yellow precipitate which formed was extracted with two 25-ml. portions of ether, and the combined extracts washed twice with 10-ml. portions of cold water. The ether solution was then dried over Drierite, and the ether evaporated on a steam cone to yield a yellow oil containing some crystals. The oil was crystallized, with the help of seeding, from 10 ml. of glacial acetic acid containing a little water. The product, washed with three 5-ml. portions of cold water, was obtained as 0.15 g. (77%) of yellow needles, m. p. 91–92° (lit.,[7b]

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[15] Dr. John Keane, private communication. This work was performed at the University of Dublin in collaboration with the late Professor T. J. Nolan and the students Misses M. P. Jones and B. Cetter and Mr. D. J. McDonnell. They proposed at that time the tentative formula $CH_3OCO(C_5H_{10})NH—P$, in which P is the pulvinyl group.

[16] Block and Bolling, "The Amino Acid Composition of Proteins and Foods," C. C. Thomas, Springfield, Illinois, 1945, pp. 237–238, 304.

[17] Microanalyses were performed by Miss Emily Davis, Miss Rachel Kopel and Mr. Maurice Dare.

92°); $[\alpha]^{20}D$ +68.6° (39 g. per 100 ml. of chloroform solution).

Anal. Calcd. for $C_{27}H_{21}O_6N$: N, 3.07. Found: N, 2.92.

Ethyl L-Norrhizocarpate (VII).—From Rhizocarpic Acid: A solution of 0.10 g. (0.0002 mole) of rhizocarpic acid and three drops of concentrated hydrochloric acid in 25 ml. of absolute ethanol was refluxed for twelve hours, then concentrated to 5 ml. Cooling produced 0.1 g. of the ethyl ester as minute yellow needles, 0.066 g. (64%) after two recrystallizations from ethanol, m. p. 170–170.5°. A mixed m. p. with rhizocarpic acid was 160–170°; with the ethyl ester described just below it was 169–171°.

From Norrhizocarpic Acid.—A solution was prepared from 0.2 g. (0.0005 mole) of the uncrystallized oily norrhizocarpic acid obtained from rhizocarpic acid, 1.0 ml. of concentrated hydrochloric acid and 50 ml. of absolute ethanol. This was refluxed for six hours, concentrated to 15 ml. and cooled to produce 0.12 g. (58%) of yellow needles, m. p. 169–170°. Recrystallization from ethanol raised the m. p. to 170–171°, $[\alpha]^{20}D$ 116.0 ± 2.2° (0.18 g. per 100 ml. of chloroform solution).

Anal. Calcd. for $C_{29}H_{25}O_6N$: C, 72.07; H, 5.17; N, 2.90. Found: C, 72.10; H, 5.19; N, 3.02.

L-Epanorin (II).—The same procedure as was employed for L-rhizocarpic acid, with 1.6 g. (0.012 mole) of L-leucine in place of L-phenylalanine, and the same quantities of the other materials, yielded 1.6 g. of crude L-epanorin, yellow needles which after one recrystallization from methanol weighed 0.91 g. (47%), m. p. 135–136°; $[\alpha]^{26}D$ −1.86 ±0.2° (6.48 g. per 100 ml. of chloroform solution). The levorotation was approximately one-half this value at 21°.

Anal. Calcd. for $C_{25}H_{25}O_6N$: C, 68.98; H, 5.74; N, 3.21. Found: C, 69.12; H. 5.71; N, 3.30.

A mixture of this compound with natural epanorin, m. p. 133.5–134.5°, melted at 133.5–134.5°.

The infrared absorption spectrum of L-epanorin in chloroform, unlike that of rhizocarpic acid, differed markedly from that of the crystalline solid (Fig. 1) in that the strong band at 1752 cm.$^{-1}$ of the solid was replaced by two medium bands at 1751 and 1772 cm.$^{-1}$.

DL-Rhizocarpic Acid (I).—The yield of amide, prepared in the same manner and with the same amounts of materials as was L-rhizocarpic acid, was 80%, yellow needles from ethanol, m. p. 144–145°.

Anal. Calcd. for $C_{28}H_{23}O_6N$: C, 71.66; H, 4.90; N, 2.99. Found: C, 71.77; H, 4.89; N, 3.01.

The infrared absorption spectrum of DL-rhizocarpic acid in chloroform solution was identical with that of the L-isomer. The spectrum of the crystalline solid differed from that of crystalline L-rhizocarpic acid in that the bands at 1740 and 1772 cm.$^{-1}$ of the L-isomer were replaced by a single band at 1754 cm.$^{-1}$ in the case of the racemic form.

Ethyl DL-Norrhizocarpate (VII).—This was synthesized in the same manner as was L-rhizocarpic acid, and with the same amounts of materials, except that the amino ester prepared was the ethyl ester of DL-phenylalanine instead of the methyl ester of L-phenylalanine. The yield was 72%, yellow needles from absolute ethanol, m. p. 143–144° (a mixed m. p. with the corresponding methyl ester, m. p. 144–145°, was 131–134°).

Anal. Calcd. for $C_{29}H_{25}O_6N$: C, 72.07; H, 5.17. Found: C, 72.26; H, 5.24.

DL-Epanorin (II).—The procedure analogous to that for L-rhizocarpic acid gave a 41% yield of DL-epanorin, yellow needles from methanol, m. p. 162–163°.

Anal. Calcd. for $C_{25}H_{25}O_6N$: C, 68.98; H, 5.74. Found: C, 68.89; H, 5.54.

The infrared absorption spectrum of DL-epanorin in chloroform was identical with that of the optically active material.

Pulvinic Acid Lactone (III) from Compounds I, II, VI and VII.—A solution of 0.1 g. (0.0002 mole) of L-rhizocarpic acid in 10 ml. of acetic anhydride was refluxed for two hours, then poured into 10 ml. of water and stirred until all the acetic anhydride had decomposed. Cooling to 5° resulted in the formation of yellow crystalline pulvinic acid lactone, 0.05 g. (74%), m. p. 219–221° (lit.,[12] 220–221°) after washing with cold water and one recrystallization from chloroform. This procedure with DL-rhizocarpic acid, ethyl L-norrhizocarpate and L-epanorin gave the same product in comparable yield. L-Norrhizocarpic acid gave the lactone, but in less than 20% yield.

Infrared Absorption Spectra.—The spectra were kindly furnished by Miss Elizabeth M. Petersen, using a Perkin-Elmer Model 12B infrared spectrometer with rock salt optics. The spectra of Fig. 1 were obtained with the crystalline pigments as Nujol mulls.

Summary

Rhizocarpic acid and epanorin, the only lichen pigments known to contain nitrogen, have been shown by synthesis to be the methyl esters of the pulvinic acid amides of L-phenylalanine and L-leucine, respectively. The synthetic materials are identical with samples of the natural pigments.

URBANA, ILLINOIS RECEIVED FEBRUARY 2, 1950

[CONTRIBUTION FROM THE CHEMICAL LABORATORIES, UNIVERSITY OF TORONTO]

Tripotassium 1,3,5-Triazacyclohexane-1,3,5-trisulfonate

BY W. P. BINNIE, H. L. COHEN AND GEORGE F WRIGHT

One of the processes developed in Germany for manufacture of Cyclonite (1,3,5-trinitro-1,3,5-triazacyclohexane, RDX) at the beginning of the second world war supposedly involved the preparation of potassium methylenesulfamate and its conversion to the explosive in 80% yield with nitric acid and sulfur trioxide.[1,2] The following reactions have been suggested as representative of this process

$$(1)\quad CH_2O + H_2NSO_3K \longrightarrow CH_2{=}NSO_3K + H_2O$$

$$(2)\quad CH_2{=}N{-}SO_3K + HNO_3 \xrightarrow{SO_3} CH_2{=}NNO_2 + KNSO_4$$

$$(3)\quad 3CH_2{=}NNO_2 \longrightarrow (CH_2{=}N{-}NO_2)_3$$

Reaction 3 of this series involves the trimerization of the hypothetical methylenenitrimine to Cyclonite. The propriety of this step seems questionable in view of earlier studies[3,4] which indicate that this monomer, if formed, decomposes at once to formaldehyde and nitrous oxide. No

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(1) W. D. Crater, *Ind. Eng. Chem.*, **40**, 1627 (1948).

(2) See also P. B. reports 925, 1820 and 80,891 (1945).

(3) W. J. Chute, *et al.*, *Can. J. Res.*, **27B**, 218 (1949).

(4) E. Aristoff, *et al.*, *ibid.*, **27B** 520 (1949).