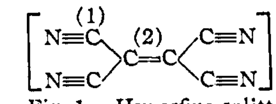

$a^N = 1.574 \pm 0.005$ gauss
$a_1^C = 9.541 \pm 0.01$ gauss
$a_2^C = 2.203 \pm 0.01$ gauss

Fig. 1.—Hyperfine splitting constants of TCNE$^-$ in DMF and in acetonitrile. These results are independent of the parent compound used to generate the radical.

These various lines of evidence prove that the primary reduction product of TCNP is TCNE$^-$. Other products are formed in small concentrations which do not give rise to an observable e.s.r. spectrum.

The d.c. polarogram of 1,1,2,2-tetracyanoethane[7] in DMF shows a long gradual wave of small slope starting at -1.1 v. At -2.0 v. there is a high, sharp wave which shows a maximum. Electrolysis at potentials below -2.5 v. produces a light yellow solution which shows no e.s.r. spectrum. At -2.5 v., violent bubbling takes place at the surface of the mercury-pool cathode, and the e.s.r. spectrum of TCNE$^-$ is obtained. Thus, just as in TCNP, the reduction product of the ethane is TCNE$^-$. The line widths in the e.s.r. spectrum obtained from the ethane are also narrower than in the spectrum obtained by starting with TCNE.

The narrowness of the lines in the e.s.r. spectrum of TCNE$^-$ obtained by the reduction of TCNP or tetracyanoethane undoubtedly arises from the absence of an electron exchange reaction between TCNE and TCNE$^-$. The excellent resolution obtained permits the identification of all the carbon-13 splittings arising from carbon-13 nuclei in natural abundance. A total of 20 lines attributable to carbon-13 nuclei is observed,[8] and these lines as well as the nine lines arising from the four equivalent nitrogen atoms, have intensity ratios which are in excellent agreement with the predicted ratios. The e.s.r. data obtained are summarized in Fig. 1. Phillips, *et al.*, found $a^N = 1.56$ gauss and $a_1^C = 6a^N = 9.4$ gauss in their original investigation.[2,8]

We wish to thank Dr. L. L. McCoy for advice regarding the chemistry of these compounds and Dr. W. H. Reinmuth for assistance with electrochemical problems and for the use of his polarographic equipment. We are indebted to Dr. T. L. Cairns of E. I. du Pont de Nemours for the original sample of TCNE.

(7) Made by the procedure given by W. J. Middleton, R. E. Heckert, E. L. Little and C. G. Krespan, *J. Am. Chem. Soc.*, **80**, 2783 (1958).

(8) W. D. Phillips and J. C. Rowell have also recently observed the carbon-13 splitting from the ethylenic carbon atoms (private communication).

(9) National Science Foundation Coöperative Fellow.

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RECEIVED JULY 31, 1961

A DEHYDROXYLATION REACTION

Sir:

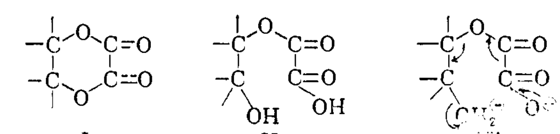
We wish to report an apparently general method for the conversion of 1,2-glycols and epoxides to olefins. The reaction consists in pyrolysing the glycol in the presence of equimolar amounts of anhydrous oxalic acid at 200–240°. To our knowledge the only recorded instance of this reaction is the well-known conversion of glycerol to allyl alcohol.[1] A typical example is the conversion of *meso*-2,3-butanediol to a mixture containing 20% *cis*- and 50% *trans*-2-butene. Less than 0.4% butadiene and less than 0.01% isomeric butenes were present in this mixture.[2]

$$CH_3—CHOH—CHOH—CH_3 \xrightarrow{\substack{COOH \\ | \\ COOH}} CH_3—CH{=}CH—CH_3$$

Alicyclic glycols smoothly undergo this conversion in yields ranging from 10–60%. Thus *cis*- and *trans*-cyclohexane-1,2-diol, *cis*- and *trans*-3,4-dihydroxytetrahydrofuran,[3] *trans*-cyclopentane-1,2-diol, as well as the corresponding epoxides were transformed into cyclohexene, 2,5-dihydrofuran and cyclopentene, respectively.

The major side reactions are those to be expected when glycols are treated with a dibasic acid namely, (a) the pinacol rearrangement: this becomes the dominating reaction with ditertiary glycols, only; (b) polyester formation: this is more pronounced with simple aliphatic glycols, *e.g.*, ethylene glycol and (c) the decomposition of the monoöxalate ester intermediate to the formate ester of the glycol.

Although the evidence is not compelling, our experiments suggest that a cyclic ester of type I is *not* the important intermediate in this reaction.



I IIa

We believe that the monoester and/or its corresponding ion pair (IIa and IIb) decompose in the concerted manner shown. The evidence rests upon these observations: (1) the cyclic oxalic ester of *trans*-cyclohexane-1,2-diol (m.p. 110.7–111.3°, *anal.*, found for $C_8H_{10}O_4$: C, 56.4; H, 5.94) when pyrolyzed furnished among other products cyclohexanone but *no* cyclohexene. (2) When anhydrous oxalic acid is added to cyclohexene oxide an exothermic reaction ensues and a *blue*[4] oil is formed. Pyrolysis of this oil discharges the blue color and furnishes, among other products, cyclohexane.

The tentative reaction scheme formalized with IIb lends itself to the following working hypothesis. Since IIb does not represent a quasi-six membered ring transition state, no great stereospecificity should be expected. Our experiments with the *cis*- and *trans*-cyclohexanediols (yielding 19

(1) O. Kamm and C. S. Marvel in H. Gilman, "Organic Syntheses," Coll. Vol. I, John Wiley and Sons, New York, N. Y., 1948, p. 45 (ref. 1 and 2).

(2) The assistance of the Shell laboratories, Amsterdam, Holland, in the analysis of this mixture is acknowledged gratefully.

(3) E. G. E. Hawkins, *J. Chem. Soc.*, 253 (1959).

(4) Compare the blue color which develops when carotenoid epoxides are treated with acid, P. Karrer and E. Jucker, *Helv. chim. acta*, **28**, 300 (1945); a conversion of epoxides to olefins *via* the iodohydrin has been achieved by J. W. Cornforth, R. H. Cornforth and K. K. Mathew, *J. Chem. Soc.*, 112 (1959). P. Bedos and A. Ruyer, *Compt. rend.*, **188**, 962 (1929), obtained traces of cyclopentane carboxaldehyde upon treatment of cyclohexene oxide with oxalic acid. G. Darzens, *ibid.*, **150**, 1243 (1910), reports the conversion of glycidic esters by treatment of hydrogen iodide to the corresponding acrylates.

and 11% cyclohexene, respectively) and *cis*- and *trans*-3,4-dihydroxytetrahydrofuran (yielding 58 and 47% of dihydrofuran, respectively) bear this out. Mono ethers and esters of 1,2-glycols, chlorohydrins and amino-alcohols might be amenable to a similar "dehydroxylation" reaction.

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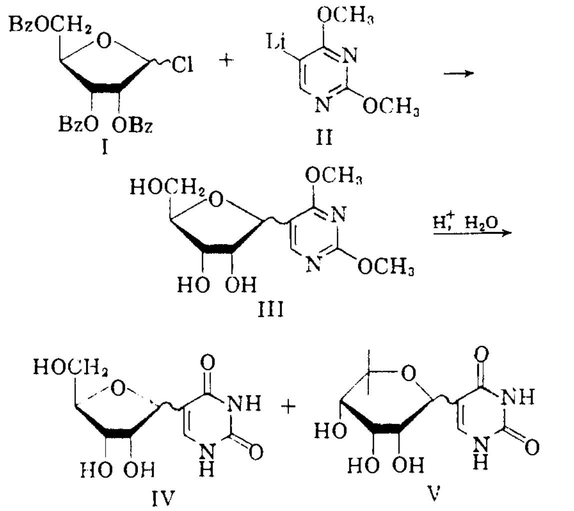
RECEIVED JULY 24, 1961

SYNTHESIS OF PSEUDOURIDINE

Sir:

Pseudouridine, a naturally occurring nucleoside,[1] is particularly interesting because of its unique structure (IV). We wish to report the first chemical synthesis of pseudouridine and to confirm the 5-D-ribofuranosyluracil structure recently assigned to it.[2]



n-Butyllithium[3] (18 mmoles) was added dropwise to 18 mmoles of 2,4-dimethoxy-5-bromopyrimidine in 50 ml. of tetrahydrofuran under rigorously anhydrous conditions at −75°. The resulting clear, yellow to reddish-brown solution of 2,4-dimethoxypyrimidine-5-lithium[4] (II) was allowed to stand for 5 minutes and then 2,3,5-tri-*O*-benzoyl-D-ribofuranosyl chloride (I),[5] (prepared from 2 mmoles of 1-*O*-acetyl-2,3,5-tri-*O*-benzoyl-β-D-ribose)[5] was added slowly (10 minutes) with stirring. The reaction mixture was stirred for 1 hour at −75° and then allowed to warm to room temperature overnight.

Water and ether were added to the solution and the two phases were separated. The aqueous layer was reextracted with ether and then neutralized with Amberlite IRC-50-H$^+$ ion exchange resin. After removal of the resin by filtration, the filtrate (4,800 optical density units at 260 mμ and *p*H 6.5, 1 cm. light path) was concentrated and poured onto a column of Dowex-1-OH$^-$ (200-400 mesh, 8% cross-linked, 4 × 16 cm.) and fractionated by elution with water. The first fraction (lithium hydroxide and a small, but variable, amount of ultraviolet-absorbing material) was discarded. Continued elution with water gave a single ultraviolet-absorbing peak. Evaporation of this solution gave a colorless gum which was assumed to be a mixture of α- and β-2,4-dimethoxy-5-D-ribofuranosylpyrimidine (III, 550 optical density units, λ_{max} 261.5 mμ, λ_{min} 240, OD_{max}/OD_{min} 2.3, R_f 0.75 in *n*-butyl alcohol–acetic acid–water (4:1:5),[6] positive periodate test for vicinal hydroxyl groups).[7] No further ultraviolet-absorbing material was eluted with water.

III (750 optical density units) was taken up in 20% (v./v.) dichloroacetic acid and hydrolyzed for 4 hours at 100° to remove the blocking groups. The residue was dissolved in 0.02 *M* H_3BO_3 adjusted to *p*H 10 with NH_4OH and poured onto a Dowex-1-HCO_3^- column (200–400 mesh, 8% cross-linked, 1 × 8 cm.). Linear gradient elution, modified from the procedure of Cohn,[2b] with 0.02 *M* H_3BO_3 (adjusted to *p*H 9 with NH_4OH) in the mixing flask and 0.05 *M* NH_4HCO_3 in the reservoir, gave five major peaks. These were identified by their ultraviolet spectra as unhydrolyzed 2,4-dimethoxy-5-D-ribofuranosylpyrimidine followed in order by the pseudouridine isomers A_F, A_S, B and C described by Cohn.[8] The fraction containing the C isomer was freed from NH_4HCO_3 with Dowex-50W-H$^+$ and from borate by repeated addition and evaporation of methanol. The solid then was purified by paper chromatography on Whatman 40 paper in *n*-butyl alcohol–acetic acid–water.[6] The major ultraviolet-absorbing band (R_f 0.24) was eluted with water and the solution was evaporated to dryness. The white solid (12 mg.) was recrystallized twice from 95% ethanol yielding 5.2 mg. (needles) of pseudouridine C. The synthetic material was identical with natural pseudouridine (isolated from urine[9]) by the following criteria: m.p. 223–224° (uncorr., reported 220–221°[2b]), mixed melting point, paper chromatography in four solvent systems,[10] paper electrophoresis in borate buffer and ultraviolet spectra compared at *p*H 2, 12 and 14.

(1) See C. A. Dekker in *Ann. Rev. Biochem.*, **29**, 453 (1960), for a recent review.

(2) (a) C. Yu and F. W. Allen, *Biochem. Biophys. Acta*, **32**, 393 (1959); J. P. Scannell, A. M. Crestfield and R. W. Allen, *ibid.*, 406 (1959); W. Cohn, *ibid.*, 569 (1959); (b) W. Cohn, *J. Biol. Chem.*, **235**, 1488 (1960).

(3) R. G. Jones and H. Gilman, *Organic Reactions*, **VI**, 339 (1951). The butyllithium solution should be clear before use.

(4) B. W. Langley, *J. Am. Chem. Soc.*, **78**, 2136 (1956).

(5) H. M. Kissman, C. Pidacks and B. R. Baker, *ibid.*, **77**, 18 (1955).

(6) S. M. Partridge, *Biochem. J.*, **42**, 238 (1948).

(7) M. Viscontini, D. Hoch and P. Karrer, *Helv. Chim. Acta*, **38**, 642 (1955).

(8) Cohn[2b] has established that naturally occurring pseudouridine (C isomer) is converted to an equilibrium mixture of pseudouridine isomers (designated A_F, A_S, B and C) by heating with acid at 100°. The periodate titration data he reports leave little doubt that the A isomers are 5-α- and 5-β-D-ribo*pyranosyl*uracil (V) and B and C are the 5-ribo*furanosyl* anomers (IV).

(9) We are indebted to Dr. Waldo Cohn for this sample (estimated by him as 75% pure). We purified it further by paper chromatography (ref. 10a) and two recrystallizations from 95% ethanol.

(10) (a) *n*-Butyl alcohol–acetic acid–water,[6] R_f 0.26; (b) isopropyl alcohol–ammonia–water (7:1:2), R. Markham and J. D. Smith, *Biochem. J.*, **52**, 552 (1952), R_f 0.40; (c) *n*-butyl alcohol–saturated with water, R. D. Hotchkiss, *J. Biol. Chem.*, **175**, 315 (1948), R_f 0.11; (d) isopropyl alcohol–1% ammonium sulfate (2:1), N. Anand, V. M. Clarke, R. H. Hall and A. R. Todd, *J. Chem. Soc.*, 3665 (1950), R_f 0.54.