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A Reinvestigation of the Ruff Degradation of a C-2 Branched Chain Saccharinic Acid

Ľ. LUKÁČ, A. KRIHOVÁ, M. MATULOVÁ, and L. PETRUŠ

Institute of Chemistry, Slovak Academy of Sciences, CS-842 38 Bratislava

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The treatment of the calcium salt of D-isosaccharinic acid with hydrogen peroxide in the presence of ferric ions gave rise to 3-deoxy-D-*glycero*-2-pentulose, the structure of which was proved by both ^{1}H and ^{13}C NMR spectroscopy. The results are in an agreement with those obtained ninety years ago by the author of the method of shortening the carbon chain of aldoses, and offer another proof, that its intermediate is not a 2-ketoaldonic acid.

Saccharinic acids are a significant part of black liquors derived from alkaline pulping processes. From among three principal types of the saccharinic acids, α- and β-D-isosaccharinic (3-deoxy-2-*C*-hydroxymethyl-D-*erythro*- and -D-*threo*-pentonic) acids prevail in the liquors. Their formation is facilitated by the 4-*O*-substitution of the parent sugar.

Several bacterial strains [1—3] have been found to be capable of utilizing saccharinic acids including D-isosaccharinic one. Chemical ways of utilization of the acids are described in a review [4]. From among them, only the preparation of 2-deoxy-D-*erythro*-pentose from α- and β-D-glucometasaccharinic (3-deoxy-D-*ribo*- and -D-*arabino*-hexonic) acids *via* the Ruff degradation is of a practical significance [5]. The observation that also D-isosaccharinic acid undergoes the degradation was published by *Ruff* himself ninety years ago [6]. The characterization of the degradation product, however, was not sufficient; in addition to its correctly assumed structure, only the stoichiometric formula of its osazone was determined. Later, all this was like forgotten and, for a long time, one had been supposing that the decarboxylation of a 2-ketoaldonic acid was an intermediate step of the Ruff degradation [7, 8]. In 1981, *Isbell* and *Salam* [9] refuted the assumption by the preparation of D-[1-^{2}H]arabinose *via* the Ruff degradation of calcium D-[2-^{2}H]gluconate. All the data evoked our interest to reinvestigate the Ruff degradation of D-isosaccharinic acid in order to learn whether it could yield an interesting deoxyketose.

Calcium D-isosaccharinate was submitted to a modified procedure of the Ruff degradation of aldonic acids by treatment with hydrogen peroxide and ferric acetate. The modification included a change of two factors. Because of a low solubility of the starting material in water, the reaction was performed in a more diluted solution. Moreover, it was necessary to initiate the degradation by heating the reaction mixture to 50—60 °C.

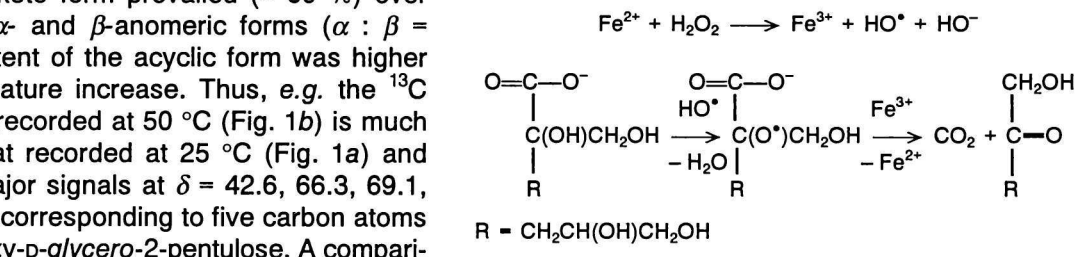
The first purification of a raw product of the degradation on a cellulose column afforded a 29 % yield of a partially purified 3-deoxy-D-*glycero*-2-pentulose still having contained small admixtures of two other reducing sugars. Chromatographically pure compound was then obtained after a purification by preparative paper chromatography in an overall 8.5 % yield. We have not succeeded to isolate two accompanying saccharides as pure compounds because of about 40 % recovery of both purification steps.

Instead of ferric sulfate, cobalt(II) and nickel(II) sulfates were also tested in the Ruff degradation of D-isosaccharinic acid. Similarly, lead(II) acetate recommended by Ruff as more convenient [6] was used to substitute usually utilized barium acetate. We have found ferric ions to be the best catalyst. The conversion of calcium D-isosaccharinate to 3-deoxy-D-*glycero*-2-pentulose in the presence of cobalt(II) or nickel(II) ions was substantially lower and reached only about 20—30 % of the conversion achieved with ferric ions. The substitution of barium acetate by lead(II) acetate did not influence the conversion.

The structure of 3-deoxy-D-*glycero*-2-pentulose was confirmed by NMR spectroscopy. In both ^1H and ^{13}C NMR spectra recorded at 25 °C, the signals of acyclic keto form prevailed (≈ 60 %) over the signals of α- and β-anomeric forms (α : β = 3 : 4). The content of the acyclic form was higher with the temperature increase. Thus, *e.g.* the ^{13}C NMR spectrum recorded at 50 °C (Fig. 1*b*) is much simpler than that recorded at 25 °C (Fig. 1*a*) and contains five major signals at δ = 42.6, 66.3, 69.1, 70.0, and 212.6 corresponding to five carbon atoms of acyclic 3-deoxy-D-*glycero*-2-pentulose. A comparison with the ^{13}C NMR spectral data of D-*erythro*-2-pentulose [10] (Table 1) was used to ascribe the ^{13}C NMR signals of α- and β-anomeric forms of 3-deoxy-D-*glycero*-2-pentulofuranose. Analysis of the ^1H NMR spectrum was made by the homocorrelated spectroscopy (COSY-45) and confirmed the same structure of 3-deoxy-D-*glycero*-2-pentulose.

The high occurrence of the acyclic form of 3-deoxy-D-*glycero*-2-pentulose in aqueous solution is a probable reason of its observed unstability; the compound apparently decomposes to two- and three-carbon molecules (glycolaldehyde, hydroxyacetone).

The results of the reinvestigation of the Ruff degradation of D-isosaccharinic acid are in accordance with the observation described by *Ruff* [6] as well as with the results obtained by *Isbell* and *Salam* [9]. Thus, the entire process of the Ruff degradation of D-isosaccharinic acid can be described as follows:



Scheme 1

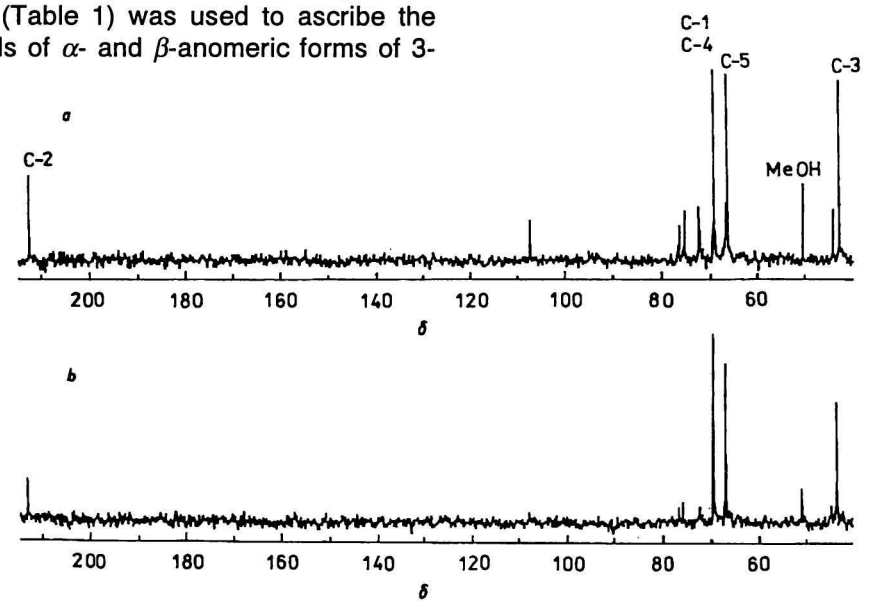


Fig. 1. ^{13}C NMR spectra (75.46 MHz) of 3-deoxy-D-*glycero*-2-pentulose in D_2O at 25 (*a*) and 50 °C (*b*).

Table 1. ^{13}C NMR Data of 3-Deoxy-D-*glycero*-2-pentulose and D-*erythro*-2-Pentulose

Compound	Form	Chemical shift δ				
		C-1	C-2	C-3	C-4	C-5
3-Deoxy-D-*glycero*-	α-furano	76.3	107.3	42.5	72.0	66.1
-2-pentulose	β-furano	75.3	107.3	43.9	72.2	66.7
	keto	69.1	212.6	42.6	70.0	66.3
D-*erythro*-	α-furano	72.4	103.8	71.4	71.7	64.0
-2-Pentulose	β-furano	72.0	106.9	73.8	71.8	63.8
	keto	67.7	213.7	77.0	76.6	62.6

EXPERIMENTAL

Chromatography was performed on a column (70 cm × 3.5 cm) of Whatman cellulose and on Whatman No. 3 paper with elution system 1-butanol—ethanol—water (volume ratio = 5 : 1 : 4). The mobilities of individual saccharides are referred to that of D-arabinose (R_{Ara} = 1.00). The ^1H NMR (300.13 MHz, internal standard sodium 3-(trimethylsilyl)propionate, δ = 0.00) and ^{13}C NMR spectra (75.46 MHz, inter-

nal standard methanol, δ = 50.15) were recorded with an FT spectrometer AM-300 (Bruker) in D_2O at 25 and 50 °C. Specific optical rotations were measured on a polarimeter 141 (Perkin—Elmer) and elemental analyses were done with an analyzer 240 (Perkin—Elmer). Solvents were evaporated under diminished pressure at temperatures under 40 °C.

3-Deoxy-D-*glycero*-2-pentulose

A stirred mixture of a solution of barium acetate (2.65 g) in water (10 cm^3), a solution of ferric sulfate (1.28 g) in water (10 cm^3), calcium D-isosaccharinate [11] (5.0 g) and water (370 cm^3) was heated to boiling and filtered. The filtrate was cooled to 40 °C and 15 % aqueous hydrogen peroxide (15 cm^3) was added. After a careful initiation (by heating the solution up to 50 °C), evolution of carbon dioxide started, causing a slight increase of temperature. After about 30 min, when the reaction temperature started to decrease, a next amount of hydrogen peroxide (15 cm^3) was added to finish the reaction within the next 30 min. Charcoal (2 g) was then added to the turbid solution. The mixture was filtered, the filtrate concentrated by evaporation (to *ca.* 50 cm^3 volume), methanol (200 cm^3) and charcoal were added, and the mixture was filtered. Ether (50 cm^3) and, after 10 min, charcoal (0.5 g) were added to the filtrate and the mixture was filtered again. The filtrate was evaporated to a sirup (3.15 g) containing four compounds with R_{Ara} = 2.20 (*I*, major product), 2.45, 1.90 (*II*, *III*; minor reducing sugars), and 0.15 (starting material).

Column chromatography of the sirup afforded fraction *1* (300—430 cm^3, 0.1 g) containing *I* and *II*, fraction *2* (430—650 cm^3, 1.0 g) containing mainly *I* with admixture of *II* and *III*, and fraction *3* (650—770 cm^3, 0.3 g) containing *I* and *III*. Following elution with ethanol afforded the starting material (0.7 g).

Preparative paper chromatography of concentrated fraction *2* afforded sirupy 3-deoxy-D-*glycero*-2-pentulose: yield = 0.28 g (8.5 %), [α](D, 20 °C, ρ = 10 g dm^{-3}, water) = – 19.4°, identical with compound *I*. For $C_5H_{10}O_4$ (M_r = 134.13) w_i(calc.): 44.77 % C, 7.51 % H; w_i(found): 44.47 % C, 7.54 % H. ^{1}H NMR spectrum of the acyclic form, δ: 4.39 (AB quartet, 2H, H-1, H-1′), $J_{1,1'}$ not resolved, 4.18 (m, 1H, H-4), $J_{3,4}$ and $J_{3',4}$ not resolved, $J_{4,5}$ = 4.4 Hz, $J_{4,5'}$ = 6.3 Hz, 4.59 (dd, 1H, H-5), $J_{5,5'}$ = 11.8 Hz, 3.59 (dd, 1H, H-5′), 2.65 (m, higher order, 2H, H-3, H-3′), $J_{3,3'}$ not resolved. ^{1}H NMR spectrum of α-anomer, δ: 4.54 (m, 1H, H-4), $J_{3,4}$ = 6.2 Hz, $J_{3',4}$ = 2.5 Hz, $J_{4,5}$ = 4.7 Hz, $J_{4,5'}$ = 3.0 Hz, 4.04 (dd, 1H, H-5), $J_{5,5'}$ = 9.8 Hz, 3.98 (ddd, 1H, H-5′), $J_{3',5'}$ = 1.0 Hz, 2.35 (dd, 1H, H-3), $J_{3,3'}$ = 14.3 Hz, 1.95 (ddd, 1H, H-3′). ^{1}H NMR spectrum of β-anomer, δ: 4.61 (m, 1H, H-4), $J_{3,4}$ = 6.2 Hz, $J_{3',4}$ = 3.1 Hz, $J_{4,5}$ = 4.4 Hz, $J_{4,5'}$ = 1.8 Hz, 4.13 (dd, 1H, H-5), $J_{5,5'}$ = 10 Hz, 3.84 (ddd, 1H, H-5′), $J_{3',5'}$ = 1.4 Hz, 2.25 (dd, 1H, H-3), $J_{3,3'}$ = 14.6 Hz, 2.13 (ddd, 1H, H-3′).

When lead(II) acetate (3.37 g) was used instead of barium acetate, a similar reaction mixture was obtained, from which, after purification, *I* (0.31 g, 9.2 %) was obtained.

By using nickel(II) or cobalt(II) sulfate heptahydrate (2.70 g) instead of ferric sulfate, the procedure again yielded pure *I* (0.10 g, 3.0 % and 0.08 g, 2.4 %, respectively).

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