The Production of Furfural from D-Lyxose and D-Ribose

BY ROBERT C. HOCKETT, ALVIN GUTTAG[1] AND MAYNARD E. SMITH[1]

The standard method for determining aldopentoses has long consisted of converting them to furfural by the action of 12% hydrochloric acid, steam-distilling the product under standardized conditions, precipitating the aldehyde as its phloroglucide and weighing the latter.[2] It is well-known that the method is not strictly quantitative in the sense that the ratio of pentose in the sample to the phloroglucide produced is not stoichiometric. Hence a standard procedure has been adopted for carrying out the reaction and tables are employed which give the equivalence between weight of phloroglucide obtained and weight of pentose taken.[3] The relation is sometimes expressed as an equation in the form

$$\text{wt. of pentose} = (a + 0.0052)C$$

where a is the weight of phloroglucide, C is a different constant for each aldopentose, and 0.0052 represents the weight of furfural phloroglucide which dissolves in 400 cc. of the solvent present under the standard conditions.

The two well-known pentoses, D-xylose and L-arabinose, give quite different values for the constant C, a difference readily apprehended by consideration of Fig. 1. To estimate accurately the pentose in a sample of material, it is obviously necessary to know its identity. Where more than one pentose is present or where the analyst does not know which is present, recourse is had to a value for "pentose" which represents a mean between the amounts of D-xylose and L-arabinose which would correspond to the weight of phloroglucide found. Such a mean value is usually included in tables under the heading "pentose."
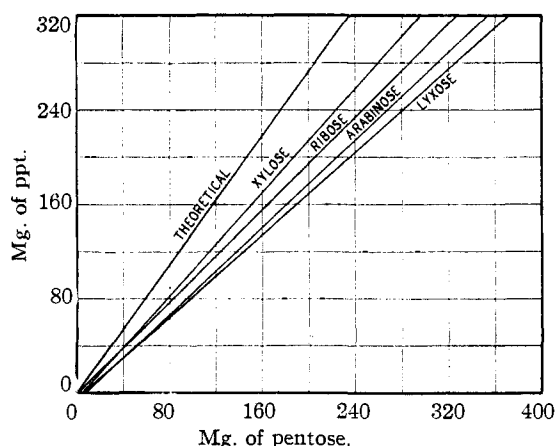

Fig. 1.—Phloroglucinol precipitate vs. pentose.

Within recent years, D-ribose derivatives have been found to occur widely, though not abundantly, in natural materials such as the nucleosides,[4] the crotonoside of castor beans,[5] cozymase[6]

(1) A study of furfural formation from D-lyxose was submitted by Maynard E. Smith as a thesis for the degree of Bachelor of Science in June, 1939. This study was repeated in part and was extended to D-ribose and the steam-distillation method by Alvin Guttag as a thesis for the Bachelor of Science degree in June, 1940. A paper including the material was read before the Division of Sugar Chemistry and Technology at the Cincinnati meeting of the American Chemical Society in April, 1940.

(2) Wheeler and Tollens, *Ann.*, **254**, 329 (1889); Methods of Analysis of the Association of Official Agricultural Chemists, Washington, 1940, p. 361.

(3) Krober. *J. Landw.*, **48**, 357 (1900).

(4) Levene and Jacobs, *Ber.*, **42**, 1198, 2102, 2469, 2476, 2703, 3247 (1909); **43**, 3147, 3150 (1910); **44**, 748 (1911).

(5) Cherbuliez and Bernhard, *Helv. chim. acta*, **15**, 464, 978 (1932).

(6) Theorell, *Biochem. Z.*, **275**, 37, 344 (1934).

and riboflavin.[7] D-Lyxose apparently has not been found in natural products but D-mannuronic acid, which would be expected to form this pentose by decarboxylation, has been found to occur abundantly in seaweeds.[8] Inasmuch as other pentoses have been found in association with the hexuronic acids so related to them in structure (D-xylose with D-glucuronic acid and L-arabinose with D-galacturonic acid) it seems very likely that D-lyxose may be encountered in some natural material.

The question of how these less common pentoses will behave when treated with 12% hydrochloric acid under the standard conditions is therefore of practical as well as theoretical interest. The present study was undertaken to answer this question. Owing to the scarcity of D-ribose, only a few points could be determined so that the work on this sugar must be regarded as preliminary.
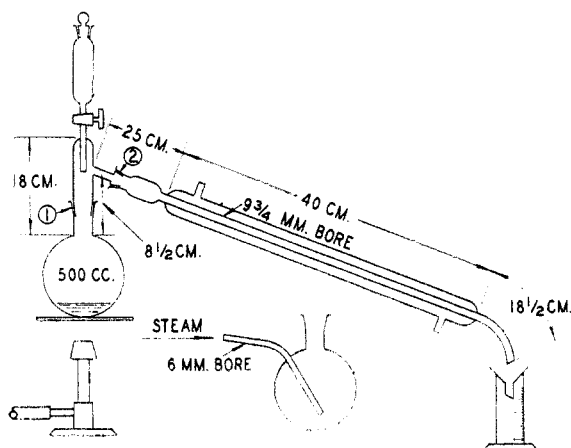

Fig. 2.

For close duplication of results, an apparatus of fixed dimensions and with ground-glass connections was found to be highly desirable. Figure 2 shows the design and dimensions of the apparatus used. The procedure was made to conform as closely as possible to the official method.[2] A practical check on both apparatus and procedure was made by running a series of determinations of the furfural produced from pure D-xylose (specific rotation +19.10) and D-arabinose[9] (specific rotation −104.5°) for comparison with the accepted values. Since these determinations were made by two different operators (A. G. and M. E.

S.) with separate samples and reagents, the results give a practical measure of the duplicability attained under ordinary laboratory conditions.

In eight determinations of furfural from D-xylose, the average deviation of the weight of phloroglucide from the quantities given in Kröber's table is 0.0016 g. In seven determinations from D-arabinose, the average deviation in weight of phloroglucide is 0.0034 g. Most of our weights are higher than those reported by Kröber.

The D-lyxose employed in this research was prepared as described by Hockett and Hudson.[9] After two hours of drying in vacuo at 70°, it melted at 103.5–104° and showed an equilibrium rotation of −13.3°[9] (C, 1.725, H$_2$O).[10] A series of twenty furfural determinations was made from samples ranging from 0.0100 g. to 0.3000 g. When the results were used to evaluate the constant in the standard equation we obtained

$$\text{D-lyxose} = (a + 0.0052) \times 1.0977$$

The average deviation of our weights of phloroglucide from the quantities calculated by this equation is 0.0046 g. By simply evaluating the constants in the equation: sugar $= a + bp$ where $p =$ wt. of phloroglucide, one obtains

$$\text{D-lyxose} = 0.0051 + 1.118p$$

The average deviation of individual values from those calculated by this formula is only 0.0031 g.

The D-ribose used in these experiments was separated from a crude sirup as its p-bromophenylhydrazone and was recovered from this derivative by the action of benzaldehyde.[11] It rotated[10] −19.6° (C, 1.122, H$_2$O) before the final recrystallization, and was dried in a vacuum over calcium chloride at room temperature. Three furfural determinations were made by the standard procedure (A. G.) and the constant was evaluated for the standard equation

$$\text{D-ribose} = (a + 0.0052) \times 0.9664$$

The average deviation from the weights of phloroglucide calculated by the equation is 0.0014 g. Evaluation of both constants in an equation of the type: sugar $= a + bp$, gives

$$\text{D-ribose} = 0.0036 + 1.027p$$

When the equation is used, the average deviation of experimental values is 0.0035 g.

Figure 1 gives a graphic picture of the relative yields of furfural from the various pentoses in

(7) Karrer, Schöpp and Benz, Helv. chim. acta, 18, 426 (1935).

(8) Nelson and Cretcaer, THIS JOURNAL, 51, 1914 (1929); 52 2130 (1930); 54, 3409 (1932).

(9) Kröber used L-arabinose in preparation of the tables but D-arabinose was available to us in a more nearly pure condition and, according to theory, the two isomers should give identical results. Cf. Hockett and Hudson, ibid., 56, 1632 (1934)

(10) All rotations cited in this paper are specific rotations of the D line of sodium at 20°.

(11) Reichstein, Helv. chim. acta, 17, 996 (1934); Steiger, ibid, 19, 189 (1936)

comparison with the theoretical. It can be concluded that D-lyxose and D-ribose will not introduce into total pentose determinations, much larger errors than those now encountered as a consequence of the difference between arabinose and xylose.

In 1932, Hughes and Acree showed that it is possible to obtain virtually quantitative yields of furfural from certain pentoses by a modified procedure. Salt was added to the reaction mixture to raise the temperature at which the reaction occurs, and the furfural was swept out with steam so that its time of exposure to the temperature of the reaction vessel was at a minimum. The furfural was determined by a volumetric method using standard "potassium bromide–potassium bromate solution."[12] In this way, it was possible to measure the rate of conversion of pentose to furfural as well as to obtain the aldehyde almost quantitatively.

Using essentially their procedure, we (A. G.), measured the rates of furfural formation from D-ribose and D-lyxose (Fig. 3). The curves are complex, but show a notable difference between these two pentoses.

(12) Hughes and Acree, Ind. Eng. Chem., Anal. Ed., 9, 318 (1937); B. Standards J. Research, 21, 327 (1938); 23, 293 (1939).
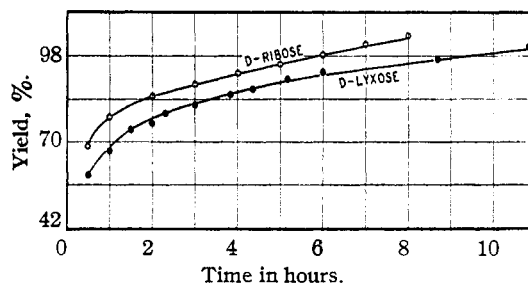

Fig. 3.—Yield of furfural vs. time of distillation.

We wish to express our indebtedness to Merck and Company of Rahway, New Jersey, for the gift of ribose sirups.

Summary

1. The standard procedure for determination of pentoses by conversion to furfural and weighing the latter as its phloroglucide has been applied to D-lyxose and D-ribose.

2. The ratio between weight of substance used and weight of phloroglucide obtained has been determined over a range from 0.0100 g. to 0.3000 g. of sugar.

3. The rates of furfural production from these sugars have been measured.

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The Alkaline Degradation of Phenylglycosides; a New Method for Determining the Configuration of Glycosides and Sugars[1]

By Edna M. Montgomery, Nelson K. Richtmyer and C. S. Hudson

The symbols α and β, originally assigned to anomeric pairs of sugars and their derivatives solely as distinguishing designations since the ring structures and the terminal configurations were not then known, are now generally in accord with the simple and logical system proposed in 1909 by one of us,[2] namely, that in the D-series of sugars the more dextrorotatory substance of an α,β-pair is designated the α-form, in the L-series the more levorotatory one is so named. This system is not wholly empirical as is sometimes stated, because it rests upon the idea that the additive rules of iso-

rotation hold with an approximation that is sufficiently close to correlate analogous configurations.

A number of methods have been proposed for determining experimentally the configuration of the glycosidic carbon atom in these α and β forms of the sugars and their glycosides.[3] Most of these methods have been attempts to decide, either by physical measurements or by chemical reactions, whether the glycosidic group is on the same or on the opposite side of the pyranoid ring in respect to a hydroxyl or other group attached to one of the other carbon atoms in the ring. The configurations of these other carbon atoms were known previously from Emil Fischer's researches.

(1) A preliminary report on the phenylglucosides was presented in part at the meeting of the National Academy of Sciences, Washington, D. C., April 29, 1941; see Science, 93, 438 (1941). The present work was presented at the Buffalo meeting of the American Chemical Society, Sept. 8, 1942.

(2) Hudson. This Journal, 31, 66 (1909); see also ibid., 60, 1537 (1938).

(3) See especially Sørensen and Trumpy, Kgl. Norske Videnskab. Selskabs, Skrifter, 1934, No. 6; Rüiber and Sørensen, ibid., 1938, No. 1; also Micheel, "Chemie der Zucker und Polysaccharide," Akademische Verlagsgesellschaft m. b. H., Leipzig, 1939, pp. 219–226.