carbon; on standing for 6 hr. at room temperature the solution gave 7.0 g. (69%) of colorless prisms, m.p. 115–117°. Two recrystallizations from ether–pentane (2:1) afforded pure tri-*O*-benzoyl-α-L-arabinofuranosyl chloride melting at 116–117° and showing $[\alpha]^{20}_{D}$ −30.6° in dichloromethane (*c* 1.2), no mutarotation being observed in this solvent over the course of 2 hr.

Anal. Calcd. for $C_{26}H_{21}ClO_7$ (480.89): C, 64.93; H, 4.40; Cl, 7.37. Found: C, 64.96; H, 4.63; Cl, 7.32.

Partial concentration of the main mother liquor, followed by the addition of pentane to turbidity, led to the crystallization of white needles melting at 125–135°. Two recrystallizations from ether gave pure tri-*O*-benzoyl-β-L-arabinofuranosyl chloride (0.35 g., 3.6%) melting at 133–135° and showing $[\alpha]^{20}_{D}$ +112.8° in dichloromethane (*c* 0.96).

Anal. Calcd. for $C_{26}H_{21}ClO_7$ (480.89): C, 64.93; H, 4.40; Cl, 7.37. Found: C, 64.69; H, 4.62; Cl, 7.32.

1,3,5-Tri-*O*-benzoyl-β-L-arabinose from Tri-*O*-benzoyl-α-L-arabinofuranosyl Chloride.—To confirm its anomeric configuration, tri-*O*-benzoyl-α-L-arabinofuranosyl chloride was hydrolyzed (with concomitant benzoyl migration) to 1,3,5-tri-*O*-benzoyl-β-L-arabinose in the following manner.[61] Tri-*O*-benzoyl-α-L-arabinofuranosyl chloride (0.14 g.) was dissolved in 5 ml. of water–acetone (1:4) and the solution observed polarimetrically. After 20 min. mutarotation had ceased and the reaction mixture was concentrated *in vacuo* to a sirup which, from ether–pentane afforded 50 mg. of crystalline material melting at 119–120°. Recrystallization from ether–pentane afforded pure 1,3,5-tri-*O*-benzoyl-β-L-arabinose, melting at 120–122° and showing $[\alpha]^{20}_{D}$ +10.1° in chloroform (*c* 1.09). Ness and Fletcher[5] reported m.p. 120–121° and $[\alpha]^{20}_{D}$ −9.7° ($CHCl_3$) for the D-enantiomorph. To confirm the identity of the substance it was acetylated with acetic anhydride in dry pyridine to give, from ether–pentane, 2-*O*-acetyl-1,3,5-tri-*O*-benzoyl-β-L-arabinose melting at 133–134° and giving $[\alpha]^{20}_{D}$ +60.5° in chloroform (*c* 0.82). Ness and Fletcher[5] reported m.p. 132–134° and $[\alpha]^{20}_{D}$ −60.4° ($CHCl_3$) for the D-enantiomorph.

Tri-*O*-benzoyl-α-D-arabinofuranosyl Fluoride.[62]—One gram of methyl α-D-arabinofuranoside tribenzoate was dissolved in 5 ml. of liquid hydrogen fluoride and the solution kept at −8° for 18 min. It was then poured onto a mixture of ice, saturated sodium bicarbonate, and dichloromethane. The organic layer was washed with cold aqueous sodium bicarbonate, dried with sodium sulfate, and concentrated *in vacuo*. From *ca.* 7 ml. of ether the tri-*O*-benzoyl-α-D-arabinofuranosyl fluoride (0.65 g., 67%) crystallized readily: m.p. 127–129°. Recrystallized twice from the same solvent, it melted at 129–130° and showed $[\alpha]^{20}_{D}$ −54.0° in chloroform (*c* 0.060).

Anal. Calcd. for $C_{26}H_{21}FO_7$ (464.43): C, 67.24; H, 4.76. Found: C, 66.95; H, 4.77.

2-Deoxy-3,5-di-*O*-*p*-nitrobenzoyl-D-*erythro*-pentosyl Bromide.—The preparative method was similar to that reported earlier for the corresponding chloride.[36] Crude methyl 2-deoxy-3,5-di-*O*-*p*-nitrobenzoyl-β-D-*erythro*-pentoside (5.04 g., $[\alpha]^{20}_{D}$ +3°) was dissolved in 30 ml. of glacial acetic acid and the cooled solution treated with a stream of hydrogen bromide for 3 min. Four minutes later, 30 ml. of ether was added and crystallization began: 2.29 g., 41%. Recrystallized from dichloromethane–ether–pentane (1:1:1), the material melted at 87–90° dec. (in bath at 80°, 9°/min.) and gave in dry dichloromethane (*c* 1.6) $[\alpha]^{20}_{D}$ +124° (extrap.), +100° (10 min.) and +94° (20 min.).

Anal. Calcd. for $C_{19}H_{15}BrN_2O_9$ (495.25): Br, 16.14; N, 5.66. Found: Br, 16.08; N, 5.54.

Acknowledgment.—The authors are indebted to Mr. Harry W. Diehl for assistance in some of the preparations. Analyses were performed by the Institute's Analytical Services Unit under the direction of Mr. H. G. McCann.

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[61] See ref. 5 for a similar reaction shown by tri-*O*-benzoyl-α-D-arabinofuranosyl bromide.

[62] This preparation was carried out several years ago in this laboratory by Dr. Christian Pedersen.

2-Deoxy-D-*erythro*-pentose. X.[1] Synthesis of 1,4-Anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol.[2] Derivative of a Furanose-related Glycal

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Received October 4, 1962

The synthesis and some of the properties of 1,4-anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol are described. As far as is known, this is the first reported example of a furanose-related glycal.

Since Fischer and Zach[3] first synthesized 3,4,6-tri-*O*-acetyl-1,5-anhydro-2-deoxy-D-*arabino*-hexose-1-enol (D-glucal triacetate), the glycals have become important as intermediates in the synthesis of a variety of carbohydrate derivatives.[4] Despite the key position which these substances occupy, the preparative method which Fischer and Zach used is still (with minor modifications[5,6]) the only significant one for the preparation of glycals, although Micheel[7] showed that the pyrolysis of certain 2,6-dideoxy-D-*ribo*-hexosides ("digitoxosides") gives 1,5-anhydro-2,6-dideoxy-D-*ribo*-hexose-1-enol ("6-deoxy-D-allal") and Zorbach and Durr[8] have recently shown that 2,6-dideoxy-3,4-di-*O*-*p*-nitrobenzoyl-β-D-*ribo*-hexosyl chloride may be dehydrohalogenated through the action of silver carbonate to a substance which is apparently the corresponding glycal.

As far as we are aware, all of the known glycals are what might be called "pyranals," derivatives of the pyranose forms of the aldoses. We wish now to describe the synthesis of a "furanal," related to 2-deoxy-D-*erythro*-pentofuranose. Attempts to apply various modifications of Fischer and Zach's[3] method to the most readily available crystalline furanosyl halide, tri-*O*-benzoyl-α-D-arabinofuranosyl bromide,[9] were without success.[10] Attention was then turned toward a wholly different approach. 3,5-Di-*O*-benzoyl-2-*O*-*p*-

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[1] 2-Deoxy-D-*erythro*-pentose. IX: A. K. Bhattacharya, R. K. Ness and H. G. Fletcher, Jr., *J. Org. Chem.*, **28**, 428 (1963).

[2] The nomenclature employed here for glycals follows one of the proposals currently under consideration by the Committee on Carbohydrate Nomenclature of the Division of Carbohydrate Chemistry of the American Chemical Society.

[3] E. Fischer and K. Zach, *Sitz. ber. kgl. preuss. Akad. Wiss.*, **16**, 311 (1913).

[4] For a review see B. Helferich, *Advan. Carbohydrate Chem.*, **7**, 209 (1952).

[5] R. E. Deriaz, W. G. Overend, M. Stacey, E. G. Teece, and L. F. Wiggins, *J. Chem. Soc.*, 1879 (1949).

[6] B. Iselin and T. Reichstein, *Helv. Chim. Acta*, **27**, 1146, 1200 (1944).

[7] F. Micheel, *Ber.*, **63**, 347 (1930).

[8] W. W. Zorbach and G. T. Durr, *J. Org. Chem.*, **27**, 1474 (1962).

[9] R. K. Ness and H. G. Fletcher, Jr., *J. Am. Chem. Soc.*, **80**, 2007 (1958).

[10] Subsequent recognition of the lability of 1,4-anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol in water made the failure of this synthetic approach readily understandable.

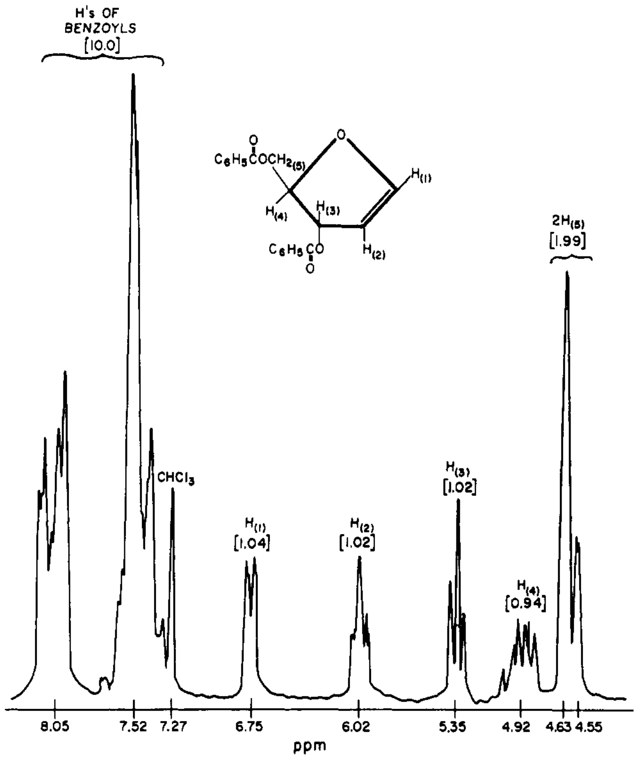
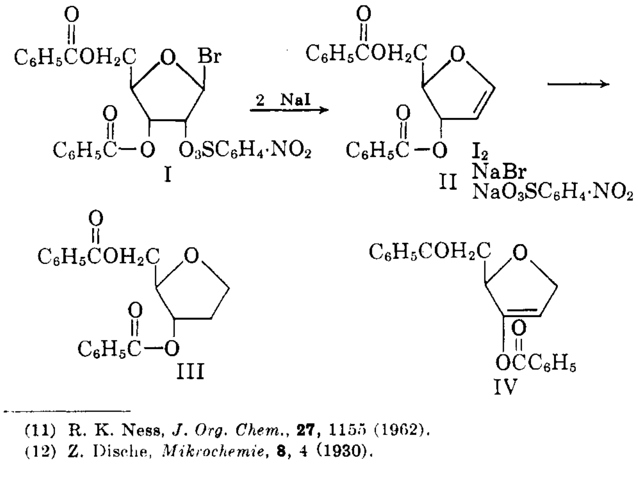


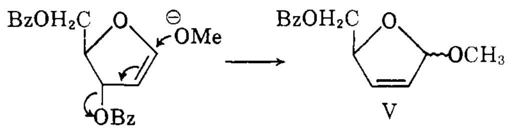
Fig. 1.—N.m.r. spectrum (60 Mc.) of 1,4-anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol in deuteriochloroform (*ca.* 0.27 *M*) using tetramethylsilane as internal standard at 0. Numbers in brackets refer to relative areas.

nitrophenylsulfonyl-β-D-ribosyl bromide (I), recently described by one of us,[11] was treated with sodium iodide in acetone solution at a low temperature. Iodine was promptly released and a precipitate, consisting of a mixture of sodium bromide and sodium *p*-nitrobenzenesulfonate, formed. The optically active moiety was readily obtained in crystalline form and found to show several of the reactions typical of the pyranose-related glycals. It gave a positive Dische test[12] for 2-deoxy sugars and rapidly decolorized solutions of bromine in carbon tetrachloride. On catalytic hydrogenation the substance was converted to a product which was found to be identical with 1,4-anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentitol (III), a compound synthesized from 2-deoxy-D-*erythro*-pentitol by Bhattacharya, Ness, and Fletcher.[1] Conversion of the glycal to III strongly suggests that the glycal has structure II but does not exclude from consideration the isomeric structure IV. However, the nuclear magnetic resonance spectrum of the glycal (Fig. 1) reveals two vinyl protons as well as other obvious features which clearly confirm structure II.



Attempts to debenzoylate II with barium methoxide failed to give a crystalline product but led to the discovery that II reacts with both water and methanol. With aqueous acetone the substance rapidly undergoes mutarotation, the initial strong dextrorotation changing to a very weak levorotation. The rate of this mutarotation appears to be little affected by the presence of traces of either acetic acid or pyridine. After the reaction of II with aqueous acetone had ceased, benzoic acid was isolated as well as an oil showing all the features of the infrared spectrum of furfuryl benzoate. Had the double bond been hydrated in normal fashion, 3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose[13] would have resulted; no evidence for the formation of this substance was obtained nor could 2-deoxy-D-*erythro*-pentose be detected after debenzoylation.

With methanol, II also released benzoic acid; in this case a second crystalline substance was isolated. This proved to be the benzoate of an unsaturated methyl glycoside; after treatment with acid it gave a positive Fehling test. On the basis of its analysis and nuclear magnetic resonance spectrum (Fig. 2), showing two vinyl protons, it appears to be a methyl 5-*O*-benzoyl-2,3-dideoxy-2-ene-D-*glycero*-pentofuranoside (V). The mechanism of its formation might be rationalized as follows[14]:



Evidence bearing on the anomeric configuration of V was not obtained. However, in view of the dextrorotatory contribution of C-4 in a D-pentofuranose derivative[1] the levorotation of the substance ($[\alpha]^{20}\mathrm{D}$ −98°) suggests that it may be a β-D-anomer.

It is possible that II may prove of utility in the synthesis of 2′-deoxynucleosides.

Experimental[15]

1,4-Anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol (II).—Sodium iodide (1.2 g., freshly dried at 177° and 0.3 mm. pressure) was dissolved in 15 ml. of acetone which had been dried over Drierite. The solution was chilled to +5° and stirred while 1.20 g. of 3,5-di-*O*-benzoyl-2-*O*-*p*-nitrophenylsulfonyl-β-D-ribosyl bromide (I)[11] was added. The bromide dissolved promptly and the brown color of free iodine became apparent almost immediately. After 4 hr. at +5°, the reaction mixture was filtered and the residue (0.72 g.[16]) washed with 15 ml. of acetone. The combined filtrate and washings were concentrated to dryness at room temperature and reduced pressure. Benzene[17] was added

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[11] R. K. Ness, *J. Org. Chem.*, **27**, 1155 (1962).

[12] Z. Dische, *Mikrochemie*, **8**, 4 (1930).

[13] M. G. Blair, D. Lipkin, J. C. Sowden, and D. R. Strobach, *J. Org Chem.*, **25**, 1679 (1960).

[14] An analogous reaction, occurring between 3,4,6-tri-*O*-acetyl-1,5-anhydro-2-deoxy-D-*arabino*-hexose-1-enol (D-glucal triacetate) and *p*-nitrophenol has been observed: R. J. Ferrier, W. G. Overend, and A. E. Ryan, *J. Chem. Soc.*, 3667 (1961).

[15] Melting points are corrected.

[16] The total theoretical yield for sodium *p*-nitrobenzenesulfonate (0.445 g.) and sodium bromide (0.204 g.) is 0.649 g. Analysis showed bromide to be present in the residue (21.40%).

[17] In the particular experiment described here, benzene was employed at this point because a Beilstein test was to be used to test for bromide; in subsequent preparations dichloromethane was found to be more satisfactory than benzene.

and the resulting solution washed with cold aqueous sodium bicarbonate containing a little sodium thiosulfate. After drying with magnesium sulfate, the halogen-free solution (Beilstein test) was concentrated *in vacuo*, the product crystallizing spontaneously. Recrystallized from a mixture of ether (10 ml.) and pentane (20 ml.), the 1,4-anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol (II, 0.46 g., 72%) melted at 88–89° and showed $[\alpha]^{20}_{\mathrm{D}}$ +294° in dichloromethane (*c* 0.5), no mutarotation being observed in this solvent over the course of 25 min. Although no decomposition was visible at its melting point, the melting point value varied somewhat with rate of heating. The substance showed a simple rotatory dispersion: 4.14 mg. diluted to 5.00 ml. with dichloromethane in a 1.00-dm. tube; 589.5 mμ, $\alpha_{\mathrm{obs.}}$ +2.40° ($[\alpha]^{20}$ +290°); 500.0 mμ, +3.74° (+451°); 435.8 mμ, +5.52° (+666°); 400.0 mμ, +7.38° (+890°); 350.0 mμ, +11.76° (+1.42° × 10^3); 300.0 mμ, +24.4° (+2.94 × 10^3); 295 mμ, +26.56° (+3.20 × 10^3); 285 mμ, +3.3° [in 1-cm. tube] (+4.0 × 10^3).

The dibenzoate is not stable on storage, decomposing to a sticky mass after a few days at room temperature; under refrigeration its stability is markedly greater.

Anal. Calcd. for $C_{19}H_{16}O_5$ (324.32): C, 70.36; H, 4.97. Found: C, 70.10; H, 4.84.

The compound rapidly decolorized solutions of bromine in carbon tetrachloride and gave a Dische test.[12] With Fehling solution a positive test was obtained after several minutes heating.

1,4-Anhydro-3,5-di-*O*-benzoyl-D-*erythro*-pentitol (III).—Palladium on charcoal (5%, 180 mg.) was suspended in 5 ml. of dioxane (freshly distilled from lithium aluminum hydride) and saturated with hydrogen. The catalyst was then removed by filtration, resuspended in 5 ml. of purified dioxane and resaturated with hydrogen. 1,4-Anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol (103.3 mg.) was then added and hydrogenation conducted at room temperature, *ca.* 10 ml. of hydrogen being absorbed (14 ml. theory) in 25 min. Filtration and concentration of the solution *in vacuo* gave 100.2 mg. of sirup which gave $[\alpha]^{20}_{\mathrm{D}}$ +43.3° in dichloromethane. Adsorption on alumina (Woelm, acid-type, grade II) and elution with benzene afforded 25.6 mg. (25%) of product (crystallized from ether–pentane) which melted at 48–49° and showed $[\alpha]^{20}_{\mathrm{D}}$ +59.1° in dichloromethane (*c* 0.45). Bhattacharya, Ness, and Fletcher[1] recorded m.p. 47–48° and $[\alpha]^{20}_{\mathrm{D}}$ +59.4° (CH_2Cl_2) for 1,4-anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentitol; a mixed melting point of the two preparations was found to be 48–49°.

Behavior of 1,4-Anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol (II) with Water.—A sample of II (m.p. 87–89°, 0.2086 g.) was dissolved in 5.00 ml. of acetone and the solution diluted with 1.00 ml. of water. The following rotations were observed at 20° in a 1.5-dm. tube: α^{20}_{D} +12.82 (1.1 min.), +12.12° (5.75 min.), +9.33° (28 min.), +0.51° (242 min.), and −0.83° (18.3 hr., constant).

In another experiment 0.2017 g. of II was dissolved in the same volumes of acetone and water with 0.10 ml. of pyridine being added α^{20}_{D} (1.5 dm. corrected to same weight and volume as above experiment): +12.72° (1.5 min.), +12.13° (5.7 min.), +8.78° (33.8 min.), +1.21° (192 min.), and −0.50° (423 min.).

In a third experiment 0.1 ml. of glacial acetic acid was used in place of the pyridine to give α^{20}_{D} (same basis): +11.80° (5.6 min.), +9.46° (21.75 min.), +2.12° (129 min.), −0.16° (251 min.), and −0.66° (6.00 hr.).

The reaction mixture from the first of the above three experiments was concentrated to dryness under reduced pressure and dichloromethane added. The solution was extracted with aqueous sodium bicarbonate, 0.0499 g. (64%) of benzoic acid being recovered on acidification of the aqueous layer. Evaporation of the dichloromethane solution gave a sirup which showed a definite hydroxyl band in the infrared but other features of its infrared spectrum were similar to those shown by an authentic specimen of furfuryl benzoate.

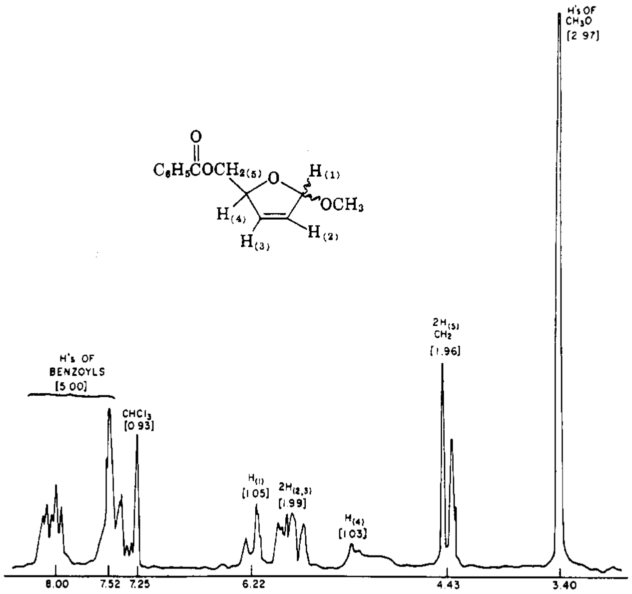

Fig. 2.—N.m.r. spectrum (60 Mc.) of methyl 5-*O*-benzoyl-2,3-dideoxy-2-ene-D-*glycero*-pentofuranoside in deuteriochloroform using tetramethylsilane as internal standard at 0. Numbers in brackets refer to relative areas.

Another experiment similar to that described above gave a 90% yield of benzoic acid; treatment of the material left in the organic layer with benzylphenylhydrazine failed to give a crystalline product. Blair, *et al.*,[13] showed that 3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose is readily converted to the benzylphenylhydrazone of 5-*O*-benzoyl-D-*glycero*-4,5-dihydroxy-2-pentenal.

Methyl 5-*O*-Benzoyl-2,3-dideoxy-2-ene-D-*glycero*-pentofuranoside (V). Crystalline II (1.495 g.) was dissolved in 10 ml. of dichloromethane and the solution diluted with 30 ml. of absolute methanol. After 23 hr., mutarotation having ceased, the solution was concentrated under reduced pressure to a white, sirupy mass (1.552 g.). This residue was dissolved in dichloromethane and the solution washed with aqueous sodium bicarbonate. Acidification of the aqueous extract provided 0.4851 g. (86% yield for one equivalent) of benzoic acid, m.p. 120–122°. Concentration of the organic layer afforded 1.0403 g. of sirup which showed $[\alpha]^{20}_{\mathrm{D}}$ −51.2° in dichloromethane. This sirup was extracted with pentane (3 × 20 ml.), it being cooled in Dry Ice prior to each decantation; the residue then crystallized spontaneously. A fourth extraction of the semisolid mass with *ca.* 150 ml. of pentane afforded, on cooling the extract overnight at −70°, 0.290 g. of crystalline material rotating $[\alpha]^{20}_{\mathrm{D}}$ −84° in dichloromethane. A portion of this material was sublimed at 100° (bath) and 0.2 mm. in 81% yield. The sublimate melted over a broad range, melting being complete by 45°[18]; it showed $[\alpha]^{20}_{\mathrm{D}}$ −98° in dichloromethane (*c* 1.8).

Anal. Calcd. for $C_{13}H_{14}O_4$ (234.24): C, 66.65; H, 6.02. Found: C, 66.42; H, 6.23.

The product rapidly decolorized a solution of bromine in carbon tetrachloride; its n.m.r. spectrum is shown in Fig. 2.

Acknowledgment.—The authors wish to express thanks to Dr. Edwin D. Becker for nuclear magnetic resonance spectra and to Mr. H. K. Miller for optical rotatory dispersion measurements.

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[18] Subsequent recrystallization of a sample of the sublimed material afforded crystals melting at 40–46°.