An Improved Synthesis of 2,4,8,10-Tetroxaspiro[5.5]undecane (Pentaerythritol Diformal)

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Pentaerythritol diformal is prepared almost quantitatively in less than ten minutes by heating up to about 120° a neat mixture of pentaerythritol with a slight excess of paraformaldehyde containing catalytic amounts of a mineral acid.

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During my investigations on phosphorylated polyols as potential aphrogenic pyrostats (2), pentaerythritol diformal was required as a prospective intermediate in phosphorylation reactions. Although the spirocyclic formal is readily prepared under acidic conditions from pentaerythritol and aqueous formaldehyde (3-6), trioxane (7,8), or paraformaldehyde (9-12), often in good yields, reaction times are in the order of several hours, and operations for its isolation can be time-consuming. The formation of the diformal from chloromethyl ethers of pentaerythritol and of 5,5-bis(hydroxymethyl)-1,3-dioxane has no synthetic value. The reaction of paraformaldehyde with paraldehyde (9) to give the diformal would be attractive were it not for the low yields, long reaction times, and tedious operations for isolating the product.

In contrast to these lengthy and tedious procedures, it is found that high yields of the diformal can be prepared conveniently in less than 10 minutes simply by heating a stirred mixture of pentaerythritol with a slight excess of paraformaldehyde up to about 120° in the presence of catalytic amounts of acid, but without any solvents or only a small amount of water. It is advantageous to carry out the reaction to two stages: first by preparing the monoformal with a molar equivalent of paraformaldehyde in about 5 minutes, and then, after cooling to about 70°, adding the remainder of paraformaldehyde in only 1% excess, and heating to about 120° for a total heating time of 10 minutes. The latter process reduces loss of formaldehyde and improves conversion. With either process, yields based on pentaerythritol exceed 90%. Catalytic amounts of acid (0.1-1.0 mole%) must be present. Hydrochloric, sulfuric, toluenesulfonic, and methanesulfonic acids, as well as boron trifluoride etherate and aluminum chloride have been used. Hydrochloric acid is used advantageously with zinc chloride, but the acid may be objectionable because of possible formation of the carcinogenic bis(chloromethyl)ether. Cadmium chloride or zinc chloride and phosphoric acid in small amounts are ineffective; only resinous products or rubbery gels are formed from which no diformal can be isolated. However, if a small amount of water is used with the zinc chloride, moderate yields of the diformal are produced, probably as a consequence of hydrolytic formation of hydrogen chloride. Although only clear resins or tough rubbery gels are produced with small amounts of phosphoric acid (<10 mole %, based on pentaerythritol), with larger amounts of the acid, the diformal is obtained in increasingly better yields (80%) when an equimolar amount of acid is present. With aluminum chloride as a catalyst, much clear viscid oil is formed and only a 35% yield of the diformal is obtained.

A small amount of water (5-10%, based on the total weight of reactants) helps in converting the paste (initially formed at about 55°) more rapidly into a fluid slurry. This simplifies stirring and permits better heat transfer. Aside from this convenience, water is not essential for good yields of product.

Small but variable amounts (generally <10%) of the hydroscopic monoformal 5,5-bis(hydroxymethyl)-1,3-dioxane are formed as a consequence of formaldehyde loss if heating is too rapid, or of volatile acids, if hydrochloric acid is used. The formals are readily isolated by distillation or, with small quantities (less than 100-g. lots), by extraction with petroleum ether or hexane in which the monoformal is insoluble. The monoformal is readily converted into the diformal by treatment with a slight excess of paraformaldehyde and heating in the presence of an acid, as described before.

Aqueous formaldehyde solutions and trioxane were used equally successfully without resorting to the long reaction times reported in the literature, but they are not as convenient to use as paraformaldehyde. Their volatility requires slower heating. In the case of formalin, much water must boil off, some formaldehyde is lost, and on a 0.1-*M* scale it takes 20-25 minutes to carry out the reaction.

No attempt was made to ascertain the best heating schedule to maximize the utilization of formaldehyde or decrease the amount of monoformal as a by-product. Casual observations suggest that the procedure described here may be applicable for preparing the monoformal in a

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few minutes but serious efforts were not made to explore the possibility at this time. There is little doubt that the procedure favorable for preparing the spiroformal of pentaerythritol will also be applicalbe to making formals of other 1,3-diols.

EXPERIMENTAL

All reagents, obtained from chemical supply houses, were used as received, but the solids were powdered if necessary. The ingredients were mixed thoroughly and the reaction mixtures stirred while heating them.

From Paraformaldehyde.

With Sulfuric Acid.

A mixture of pentaerythritol (40.8 g.), paraformaldehyde (20.0 g.), and 5 drops of concentrated sulfuric acid was heated in about 10 minutes to 145° and maintained at this temperature until ebullition ceased (about 5 minutes). On cooling to room temperature, the clear liquid solidified exothermally into a crystalline mass (48.6 g.). Extraction with boiling petroleum ether and distillation of the extracts left the diformal as white needles (33.1 g., m.p. 49-50°). The immiscible oil remaining was mixed with 1.5 g. of paraformaldehyde and heated rapidly to 150° for a total of 10 minutes. Work-up as before gave a second crop of diformal (11.2 g., m.p. 49-50°) for a total yield of 92%, based on pentaerythritol. The diformal, 2,4,8,10-tetraoxaspiro-[5.5]undecane, is reported to melt at 50° after softening at 45° (3a).

The mixture of pentaerythritol (13.0 g.), paraformaldehyde (3.1 g.), and 2.0 g. of 25% sulfuric acid was heated in 1 minute to 105°. The paste initially formed at 65° became a thin slurry at 70° and a clear liquid at 105°. After 2 minutes at 105-110° and another 2 minutes at 115-120°, the liquid was cooled to 80° and an additional 3.1 g. of paraformaldehyde was added. Heating was continued as before, and the reaction mixture then cooled to get a crystalline white solid (15.8 g., m.p. 45-48°). Extraction as before gave 14.5 g. of the diformal.

With Hydrochloric Acid.

When a mixture of 13.6 g. of pentaerythritol, 6.2 g. of paraformaldehyde, and 0.5 ml. of 37% hydrochloric acid was heated, it passed through a paste at 50°, a thick slurry at 60°, thinning out at 70° and a clear liquid at 105°, all in 2 minutes. The liquid boiled at 110-120° but became quiescent within 4 minutes, after which the temperature was raised briefly to 135-145° for a total heating time of <10 minutes. The clear colorless reaction product (15.0 g.) solidified to a crystalline mass (37-42°) on cooling. Extraction with petroleum ether gave 14.0 g. of the diformal (m.p. 50°).

With Phosphoric Acid.

A mixture of 13.6 g. of pentaerythritol, 6.8 g. of paraformaldehyde, and 1.23 g. of 18% aqueous phosphoric acid was heated in 2 minutes to 110°, when some boiling occurred and a clear liquid resulted. The temperature was raised to 115-125°; the liquid became increasingly more viscous and finally converted into a tough, tacky, rubbery gel (16.3 g.) after being heated 8 minutes. The product was insoluble in methylene chloride, diethyl ether, ethanol, or water. No diformal could be extracted from the resin. Similar results were obtained with an equivalent amount of 85% phosphoric acid.

When 11.0 g. of 85% phosphoric acid was used instead of 1.23 g. of 18% aqueous phosphoric acid and the reactants heated as before, a viscous liquid miscible in ether was obtained. Extraction with methylene chloride (5 x 25 ml.) and distillation of the extracts left 12.5 g. of the diformal, m.p. 46-48°; the low melting point is probably due to presence of some monoformal. The residual oil (12.7 g.) expanded to about 20 X into a black foam on exposure to a flame.

From Trioxane.

The slurry obtained at 100° from a mixture of pentaerythritol (13.6 g.), trioxane (6.3 g.), and 4 drops of concentrated sulfuric acid became a limpid liquid after 5 minutes at 110°. The temperature was raised to 150° during which much ebullition occurred; heating was continued for 5 minutes. The total heating time was 20 minutes. Extraction of the cooled mixture with petroleum ether gave 5.7 g. of white needles, m.p. 48-50°. When heated rapidly with 1.5 g. of paraformaldehyde (heating time 10 minutes) and worked up as before, the residual oil (8.6 g.) gave another crop of diformal, 6.7 g., m.p. 48-50°.

From 37% Formaldehyde Solution.

A slurry of 13.7 g. of pentaerythritol, 18.3 g. of 37% formaldehyde solution, and 1.5 ml. of concentrated hydrochloric acid was heated to boiling in 7 minutes and the resultant clear solution boiled for about 8 minutes, when all the water was gone. The temperature was raised to and maintained at 125° for 3 minutes. The waxy solid formed on cooling was extracted with petroleum ether to give the diformal (10.2 g., m.p. 49-50°). The residual oil (4.7 g.) was discarded.

REFERENCES AND NOTES

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(2) These are substances having the inherent property of expanding by chemical transformation into thermally insulative heat- and fire-resistant foams or sponges upon exposure to heat above some critical temperature.. Unpublished exploratory work on such materials has been carried out at Armstrong Cork Company.

(3a) M. Schulz and B. Tollens, *Ber.*, 27, 1892 (1894). (b) *Idem.*, *Ann. Chem.*, 289, 20 (1898).

(4) J. Read, *J. Chem. Soc.*, 101, 2090 (1913).

(5) J. Janku, Z. Cervanka and S. Duras, Czechloslovakian Patent 107,978 (1963); *Chem. Abstr.*, 60, 5338c (1964).

(6) C. S. Rondestvedt, *J. Org. Chem.*, 26, 2247 (1961).

(7) A. Skrabal and M. Zlatewa, *Z. Physik, Chem.*, 119, 305 (1926).

(8) J. Lichtenberger and L. Martin, *Bull. Soc. Chim. France*, 468 (1947).

(9) H. J. Prins, *Rec. Trav. Chim.*, 71, 1131 (9152).

(10) G. Schneider and O. Kovacs, *Acta Phys. Chem. Szeged.*, 10, 95 (1964).

(11) G. Alwinn, F. Brunnmüller and K. Martin, German Patent 1,135,878 (1962).

(12) L. Coes, U. S. Patent 2,526,601 (1950).