solution which was distilled in a closed system through an 18-in. Vigreux column into a receiving flask cooled in Dry Ice–acetone. The first fraction collected (*ca.* 1 ml.) was injected into a Perkin-Elmer Vapor Fractometer (Model 154C) containing a column packed with polypropylene glycol. The instrument was fitted with a flame ionization detector, the carrier gas was nitrogen and the temperature was maintained at 100°. The resulting chromatogram contained, in additional to strong methanol absorption, a relatively sharp peak with retention time of 2.04 min. An essentially identical peak, with the same retention time, was observed in the spectrum of a solution of methanol through which dimethyl ether (Matheson Co.) had been bubbled for 5 min. immediately prior to injection.

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Rearrangement of Lactones from Substituted 3-Hydroxycyclohexanecarboxylic Acids[1]

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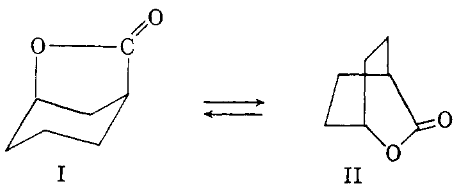
The rearrangement of hydroxy acids (or lactones) is well known, particularly in complex ring systems. In the chemistry of the diterpenes and resin acids several examples have recently been clarified.[4]

In connection with other studies[5,6] we have had occasion to observe examples of rearrangement in simple cyclohexane derivatives.

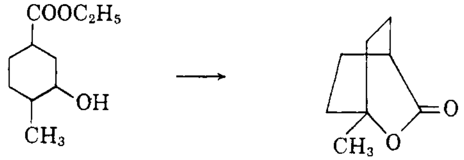
The first example is the rearrangement of the lactone of *cis*-3-hydroxycyclohexanecarboxylic acid (I) upon standing in concentrated sulfuric acid at room temperature. Though the recovery of material is not high, the predominant product is the lactone of *cis*-4-hydroxycyclohexanecarboxylic acid (II). The change from the bicyclo[3.2.1]octane system to the [2.2.2] bicyclic system is somewhat unusual.



I II

In comparable carbocyclic compounds, 2-bromobicyclo[2.2.2]octane rearranges to 2-bromobicyclo[3.2.1]octane,[7] upon treatment with silver ion under what are presumably equilibrium conditions. Similarly[8] hydration of bicyclo[2.2.2]octene affords bicyclo[3.2.1]octanol-2 in good yield. In both cases it has been suggested that relief of bond oppositions provides a rationale for the change from the [2.2.2] system to the [3.2.1] system. On the other hand, the addition of acetic acid to bicyclo[3.2.1]-octene-2 gives bicyclo[2.2.2]octyl acetate.[9]

In the second example, we treated ethyl 3-hydroxy 4-methylcyclohexanecarboxylate with 50% sulfuric acid, under conditions which were designed to lead to lactone formation. The product of this reaction of m.p. 68–69° ($C_8H_{12}O_2$) is a δ-lactone from its infrared spectrum, and is therefore assigned structure IV.



III IV

Lehman and Paasche[10] have reported a byproduct of m.p. 69° from the Diels-Alder reaction of isoprene and acrylic acid, to which they assign the structure of 4-methyl-3-hydroxycyclohexanecarboxylic acid lactone(V). However, neither isomer of V melts at 69°[6] and it appears highly probably that the compound of Lehman and Paasche is IV.

EXPERIMENTAL[11]

4-Methyl-cis-4-hydroxycyclohexanecarboxylic acid lactone Reduction of ethyl 3-hydroxy-4-methylbenzoate with Raney nickel and hydrogen afforded a mixture of the lactones of 4-methyl-*cis*-3-hydroxycyclohexanecarboxylic acid and the ethyl-4-methyl-3-hydroxycyclohexanecarboxylates.[6] This mixture (43 g.) was heated at 45° for 16 hr. with 200 ml. of 50% sulfuric acid. The reaction mixture was diluted and extracted with ether. The ether extracts were washed with 10% sodium carbonate solution, water, and then dried. Distillation afforded a fraction, b.p. 100–130° (7 mm.) which solidified. Recrystallization from pentane afforded the lactone of 4-methyl 4-hydroxycyclohexanecarboxylic acid, m.p. 68.0–

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[1] Studies of Configuration X. Previous paper, D. S. Noyce and B. N. Bastian, *J. Am. Chem. Soc.*, **82**, 1246 (1960). Supported in part by a grant from the National Science Foundation (NSF-G5921).

[2] Eastman Kodak Company Fellow, 1954–55.

[3] Dow Chemical Corporation Fellow, 1958–59.

[4] *Cf.* L. J. Gough, T. F. Sanderson, V. I. Stenberg, and E. Wenkert, *J. Org. Chem.*, **25**, 1269 (1960); E. Wenkert and J. W. Chamberlain, *J. Am. Chem. Soc.*, **81**, 688 (1959).

[5] D. S. Noyce and H. I. Weingarten, *J. Am. Chem. Soc.*, **79**, 3098 (1957).

[6] D. S. Noyce and L. J. Dolby, abstracts of papers presented at the 136th Meeting of the American Chemical Society, Atlantic City, N. J., September 1959, *J. Org. Chem.*, **26**, 1732 (1961).

[7] W. v. E. Doering and M. Farber, *J. Am. Chem. Soc.*, **71**, 1514 (1949).

[8] M. S. Newman and Y. T. Yu, *J. Am. Chem. Soc.*, **74**, 507 (1952). *Cf.* A. A. Youssef, M. E. Baup, and H. M. Walborsky, *J. Am. Chem. Soc.*, **81**, 4709 (1959).

[9] K. Alder, H. Kniger, and H. Weiss, *Ber.*, **88**, 144 (1955).

[10] E. Lehman and W. Paasche, *Ber.*, **68**, 1068 (1935).

[11] Melting points are corrected; boiling points are uncorrected. Infrared spectra were determined using a Baird Model B Infrared Spectrophotometer.

68.7°. The infrared spectrum showed a strong band at 1740 cm.$^{-1}$ (δ lactone).

Anal. Calcd. for $C_8H_{12}O_2$: C, 68.54; H, 8.63. Found: C, 68.41; H, 8.81.

Behavior of the lactone of cis-3-hydroxycyclohexanecarboxylic acid in concentrated sulfuric acid. Fifteen grams of the lactone of *cis*-3-hydroxycyclohexanecarboxylic acid was dissolved in 50 ml. of concd. sulfuric acid and allowed to stand at room temperature for 48 hr. At the end of this period the opaque brown mixture was poured into water and continuously extracted with ether. The extracts were dried, evaporated, and the product fractionally distilled. The main fraction, b.p. 115° (8 mm.) weighing 4.2 g. (28%) was obtained and proved to be the lactone of *cis*-4-hydroxycyclohexanecarboxylic acid. One crystallization from ether-pentane yielded 3.3 g. of lactone melting over a range to 124°. Crystallization of a small sample gave material of m.p. 127–128°, (lit.[12] m.p. 126–128°). The infrared spectrum was identical with that of an authentic sample of *cis*-4-hydroxycyclohexanecarboxylic acid lactone.[13]

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[12] N. R. Campbell and J. H. Hunt, *J. Chem. Soc.*, 1379 (1950).

[13] D. S. Noyce, G. L. Woo, and B. R. Thomas, *J. Org. Chem.*, **25**, 260 (1960).

Preparation of Methyl β-Hydroxybutyrate from Propylene Oxide, Carbon Monoxide, Methanol, and Dicobalt Octacarbonyl

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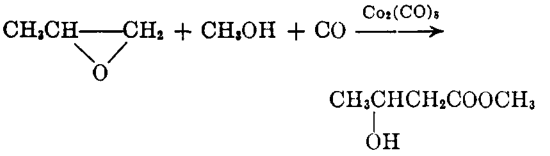
The oxo reaction[1] is a well known method for converting olefins to aldehydes or alcohols by hydroformylation, using carbon monoxide, hydrogen, and a cobalt catalyst. When water, alcohols, or amines are used as the source of hydrogen,[2] the products are acids, esters, and amides, respectively. This paper reports the results from the reaction of propylene oxide with methanol and carbon monoxide in the presence of dicobalt octacarbonyl under the conditions of temperature and pressure used in oxo syntheses.

Very little has been published concerning the reaction of the epoxy structure with carbon monoxide. Hamada, Baba, and Hagihara[3] treated ethylene oxide with carbon monoxide and hydrogen in toluene using dicobalt octacarbonyl as catalyst and obtained a mixture of products all of which resulted from the reaction of the oxide with hydrogen only. Lenel[4] reported that in the oxo reaction, epoxides other than ethylene oxide gave rise to mixtures of isomers which proved extremely difficult to separate. Seon and Leleu[5] claimed the preparation of monoethylene glycol hydracrylate from ethylene oxide, carbon monoxide, and water and of mixtures of hydracrylates by replacing the water with alcohols. Apparently nothing has been reported concerning the reaction of unsymmetrical epoxides with carbon monoxide.

Propylene oxide in methanol as solvent reacted with carbon monoxide in the presence of preformed dicobalt octacarbonyl to give predominantly methyl β-hydroxybutyrate.



$$CH_3CH\underset{O}{-}CH_2 + CH_3OH + CO \xrightarrow{Co_2(CO)_8} \underset{\displaystyle OH}{CH_3CH}CH_2COOCH_3 \quad \text{I}$$

Under the conditions used, minor amounts of 1-methoxy-2-propanol and 2-methoxy-1-propanol were also formed together with very small amounts of unidentified hydroformylation products, one of which is probably methyl crotonate. Table I presents the reaction conditions and results of several typical runs.

In addition to the products shown, gas chromatographic analysis indicates that traces of methyl β-hydroxyisobutyrate may have been produced in some of these experiments. Larger scale runs support this, but in no case could the isobutyrate consist of more than 5% of the total ester formed. Polymeric material derived from the condensation of the hydroxyester or the polymerization of propylene oxide was not found; neither was the formation of any monopropylene glycol hydroxybutyrate noted.

The structure of I was proved by the identity of its infrared spectrum and the melting point of its amide to the corresponding data from authentic methyl β-hydroxybutyrate. In addition, oxidation of I with potassium dichromate yielded methyl acetoacetate, also identified by infrared spectra and the preparation of comparison of suitable derivatives. Confirmation of the structure of I was also made by comparison of its gas chromatogram to that of authentic hydroxybutyrate.

Identification of the two methoxypropanols was made by means of their retention times determined from gas chromatograms and by infrared spectra. Data procured by both of these methods were identical to those obtained from the two propanols when synthesized by an independent route.

The results in Table I indicate that the reaction occurs over a fairly wide range of conditions but highest yields are obtained by heating at 130° for about four hours with an initial carbon monox-

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[1] I. Wender, H. W. Sternberg, and M. Orchin, *Catalysis*, Vol. V, P. H. Emmett, ed., Reinhold Publishing Corp., New York, 1957, p. 173.

[2] G. Natta, P. Pino, and R. Ercoli, *J. Am. Chem. Soc.*, **74**, 4496 (1952).

[3] K. Hamada, K. Baba, and N. Hagihara, *Mem. Inst. Sci. and Ind. Research*, Osaka University, **14**, 207 (1957).

[4] P. O. Lenel, *Proc. Chem. Soc.*, 50 (1958).

[5] M. Seon and J. Leleu, U. S. Patent 2,782,226 (1957).