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Preliminary communication

Concurrent oxidation and reduction reactions of cyclohexanehexone, rhodizonic acid, and tetrahydroxy-1,4-benzoquinone with hydrogen peroxide*

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In continuation of a study of the formation and decomposition of hydroperoxides[1–5], the reactions of cyclohexanehexone (**1**), rhodizonic acid (**2**), and tetrahydroxy-1,4-benzoquinone (**3**) have been studied. It was expected that these compounds would form hydroperoxide adducts which would decompose by cleavage reactions similar to those found for carbohydrate derivatives. In aqueous sodium peroxide solution, under conditions similar to those used for study of the degradation of aldoses and other carbohydrates, all three compounds yielded carbon dioxide, formic acid, oxalic acid, and hydroxymalonic (tartronic) acid. Production of formic and hydroxymalonic acids from **1** was most surprising, because these products have carbon–hydrogen bonds whereas **1** does not have any. Thus, in the degradation process, one or more of the carbonyl groups of **1** must have been reduced.

It was found experimentally that addition of aqueous sodium peroxide to a solution of **1** results in the evolution of oxygen and the development of a dark-yellow color characteristic of a solution of sodium rhodizonate. Formation of rhodizonic acid was confirmed by dropwise addition of aqueous sodium peroxide to a solution of **1** containing barium chloride. As the reaction proceeded, the brick-red salt of barium rhodizonate precipitated. Reduction of one of the carbonyl groups of **1** would give hydroxycyclohexanepentone (**4**), the keto form of **2**, whereas reduction of two carbonyl groups of **1** would give 5,6-dihydroxy-1,2,3,4-cyclohexanetetrone (**5**), the keto form of **3**. The reaction, hereinafter called a "hydroperoxide reductive decomposition", involves formation of a hydroperoxide adduct and free-radical decomposition of this, with elimination of a molecule of oxygen.

In the presence of barium cations, **1** may be reduced directly to **2** by the mechanism of Scheme 1. The mechanism involves formation of the bis-hydroperoxide adduct **6**, and attack on one of the hydroperoxide groups by a hydroperoxide radical, followed by decomposition of the resulting radical (**7**) with elimination of a molecule of oxygen and a hydro-

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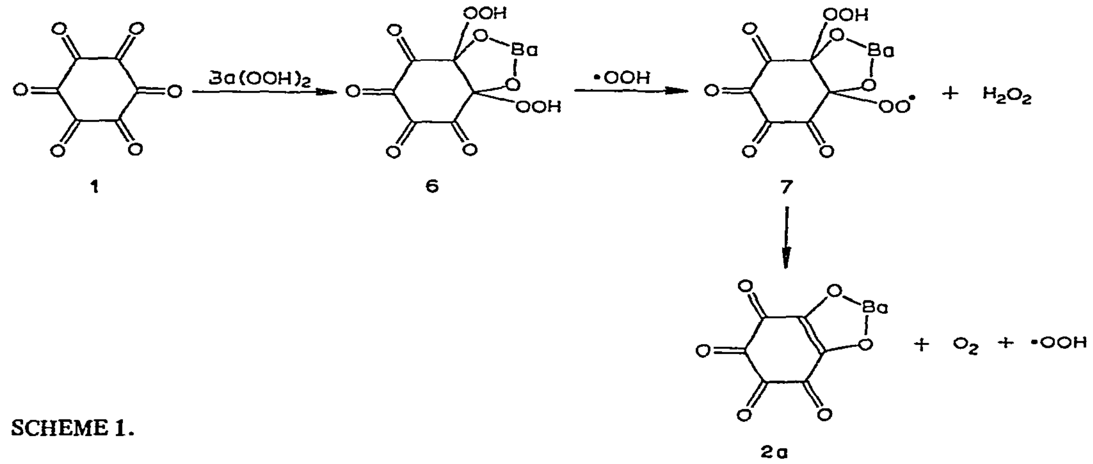
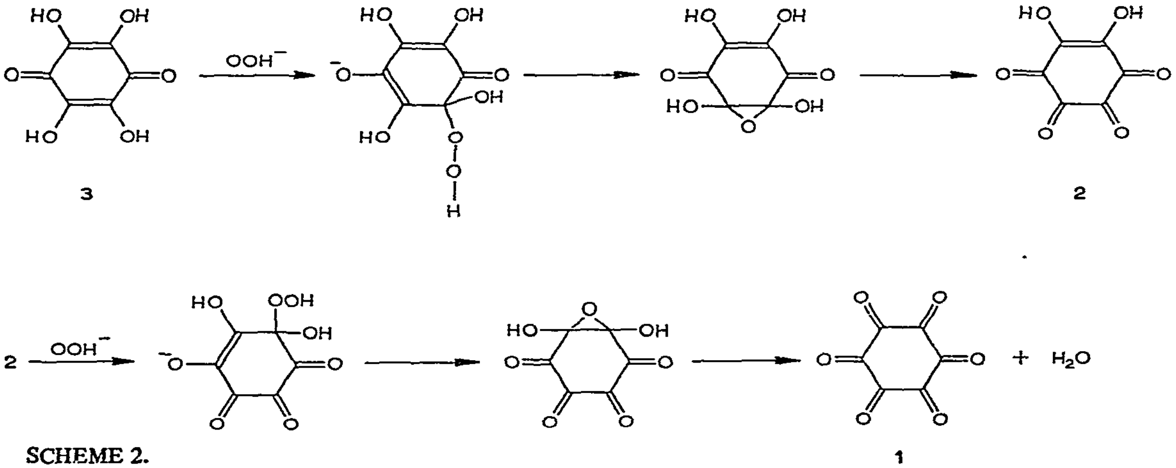
*Reactions of Carbohydrates with Hydroperoxides. Part V. For Parts I, II, III, and IV, see refs. 1–4.



SCHEME 1.

peroxide radical, leaving a molecule of barium rhodizonate (2a). Production of 2a proved that alkaline hydrogen peroxide *reduces* 1 to 2, whereas the experiments described later prove that alkaline hydrogen peroxide *oxidizes* 3 to 2; and 2 to 1.

Dropwise addition of an aqueous solution of sodium peroxide to a solution of 3 in aqueous 1,4-dioxane resulted in a change in the color of the solution from cherry-red to very dark-brown, to yellow, to colorless. The changes in color are in accord with successive production of 2 and 1. Production of 2 was confirmed by dropwise addition of aqueous sodium peroxide to a solution of 3 containing barium chloride; after addition of slightly over 1 mole of sodium peroxide per mole of substrate, the difficultly soluble barium salt of 2 was precipitated in almost quantitative yield. Production of 1 was established by addition of sufficient aqueous sodium peroxide to an aqueous solution of the potassium salt of 2 to



SCHEME 2.

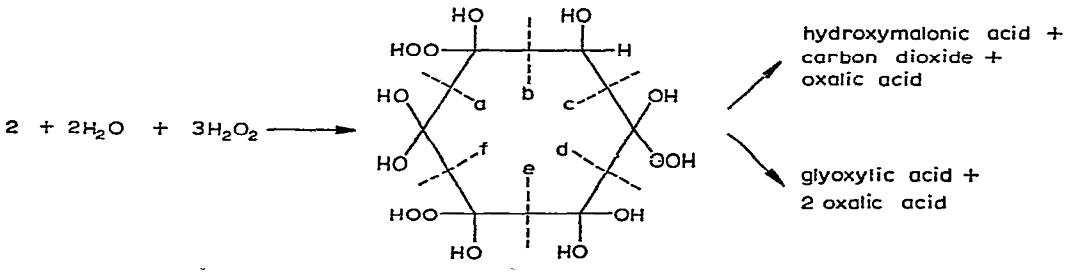
TABLE I

OXIDATION OF CYCLOHEXANEHEXONE (1), RHODIZONIC ACID (2), AND TETRAHYDROXY-1,4-BENZOQUINONE (3) AT 4° BY SODIUM PEROXIDE

Substrate	*Millimoles of product per millimole of substrate*			
	CO_2	*Formic acid*	*Oxalic acid*	*Hydroxymalonic acid*
1	0.94	0.85	1.37	0.49
2	1.14	0.88	1.74	0.18
3	1.01	0.46	1.37	0.31

yield a colorless solution; the solution was treated with a cation-exchange resin (to remove sodium and potassium ions), and evaporation then gave the crystalline octahydrate of **1**. Plausible mechanisms for the oxidation of **3** to **2**, and of **2** to **1** are depicted in Scheme 2.

With an excess of aqueous sodium peroxide, compounds **1**, **2**, and **3** were degraded completely and gave the products reported in Table I. Complete degradation of these compounds involves concurrent oxidation and reduction reactions. The reductions presumably take place by free-radical reactions, as already described, and the oxidations by ionic reactions similar to those proposed for degradation of carbohydrates[1—4]. Apparently, **1** is converted by reduction into **2** prior to cleavage of the cyclohexane ring. Compound **2** has four carbonyl groups, all of which may form intermediate hydroperoxides or hydrates. The products isolated suggest a reaction sequence beginning with the mixed hydroperoxide-hydrate adduct (**8**) depicted in Scheme 3. *alpha*-Hydroxy peroxide cleavage of a molecule of **8** at a, d, and f would give one molecule each of hydroxymalonic acid, carbon dioxide, and oxalic acid, whereas, cleavage of a molecule of **8** at a, c, and e would give two molecules of oxalic acid and one molecule of glyoxylic acid. The glyoxylic acid would be converted into carbon dioxide and formic acid; hence, the ultimate products would be 2 molecules of oxalic acid, 1 molecule of formic acid, and 1 molecule of carbon dioxide. Experimentally, degradation of **2** gave hydroxymalonic acid in an amount corresponding to 18% of the substrate. If it is assumed that 18% of **2** reacted by way of hydroxymalonic acid, and 82% by way of formic acid, the yields of carbon dioxide and oxalic acid should have been, respectively, 1.0 and



SCHEME 3

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1.82 moles per mole of substrate. The values found, 1.14 and 1.74 moles, are in reasonably good accord with the values calculated. The slightly high experimental value for formic acid suggests that a small part of the carbonyl groups was reduced during the degradation.

The combined yield of formic acid and hydroxymalonic acid from **1** was 1.34 moles per mole of substrate. As already mentioned, production of formic and hydroxymalonic acids from **1** requires reduction of one or more of the carbonyl groups. Reduction of one carbonyl group prior to oxidative degradation would give a combined yield of formic and hydroxymalonic acids of one mole per mole of substrate, whereas reduction of two carbonyl groups would give a combined yield of two moles per mole. The combined yield found indicates that 1.34 of the 6 carbonyl groups of compound **1** were reduced prior to, or during, the oxidative degradation.

The results indicate that **1** and **2** form a system in which the substrate is alternately reduced and reoxidized by hydrogen peroxide, with liberation of oxygen. The capacity of the system to decompose hydrogen peroxide suggests use of the compounds as anti-oxidants, or as models for study of catalase-type reactions.

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