ethanol gave the corresponding mixture of *Z* alcohol **2** and its *E* isomer **9** in a quantitative yield. Aldehydes **3** and **4** could be separated[9] prior to this step or alcohols **2** and **9** would have to be isolated after reduction.

Experimental Section

All boiling points are uncorrected. Infrared spectra were determined with a Perkin-Elmer Model 137 spectrometer. NMR spectra were determined in deuteriochloroform solution on Varian Associates spectrometers, Models A-60 or XL-100. Line positions are given in δ scale, with tetramethylsilane as an internal standard. Mass spectra were recorded on an Atlas CH-4B or Associated Electrical Industries MS-902 spectrometer, high resolution measurements being determined with the latter instrument.

3,3-Dimethylcyclohexanone Diethyl Ketal (7). 3,3-Dimethylcyclohexanone (**6**) (6.54 g, 51.0 mmol), triethyl orthoformate (8.98 g, 60.6 mmol), and *p*-toluenesulfonic acid (6 mg) in 38 mL of anhydrous ethanol were stirred at room temperature for 64 h. Enough ethanolic NaOEt was added to neutralize the reaction mixture and the latter was concentrated under vacuum. Fractional distillation through a spinning-band column gave 9 g (87%) of pure 3,3-dimethylcyclohexanone diethyl ketal (**7**): bp 82–83 °C (13 mm); IR (neat) 1385, 1359 (-$C(CH_3)_2$), 1195, 1174, 1119, 1093, 1058 cm^{-1} (COCOC); ^1H NMR ($CDCl_3$) δ 0.95 (s, 6 H, geminal CH_3), 1.14 (t, 6 H, J = 7 Hz, CH_3CH_2–), 1.49 (s, 2 H, $(RO)_2CCH_2C(CH_3)_2$), 3.45 (q, 4 H, J = 7 Hz, CH_3CH_2–); mol wt 200.1777 (calcd for $C_{12}H_{24}O_2$: 200.1776).

2-(1-Ethoxy-3,3-dimethylcyclohexyl)-1,1-diethoxyethane (8). In a three-necked flask equipped with a rubber septum and a dry ice condenser protected with a calcium chloride tube are placed 3,3-dimethylcyclohexanone diethyl ketal (**7**) (7.37 g, 36.9 mmol) and 3 mL of a solution of 10% $ZnCl_2$ in ethyl acetate. The mixture was stirred and maintained at a temperature of 45 °C while 3.8 mL of ethyl vinyl ether (40.5 mmol) was added dropwise with a syringe. After the addition was completed the mixture was stirred for 2 h at 45–50 °C (bath temperature) and then allowed to come to room temperature. The mixture was diluted with ether and washed with a solution of 5% NaOH and the ethereal layer was dried over Na_2CO_3. Filtration and removal of the solvent gave 9.45 g (94%) of 2-(1-ethoxy-3,3-dimethylcyclohexyl)-1,1-diethoxyethane (**8**), which was purified by distillation using a spinning band column: bp 79–80 °C (0.5 mm); IR (neat) 2950, 1389, 1370, 1183, 1124, and 1064 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.86 and 1.05 (two singlets for geminal methyl group), 1.12 and 1.18 (t, 3 H, CH_3CH_2O), 1.74 (d, 2 H, J = 4 Hz, $EtOCCH_2CH(OEt)_2$), 3.2–38 (m, 6 H, OCH_2CH_3), 4.68 (t, 1 H, J = 4 Hz, $CH(OEt)_2$).

Preparation of (*Z*)-3,3-Dimethyl-$\Delta^{1,\alpha}$-cyclohexaneacetaldehyde(3) and (*E*)-3,3-Dimethyl-$\Delta^{1,\alpha}$-cyclohexaneacetaldehyde (4). To acetal **8** (950 mg, 3.4 mmol) dissolved in 10 mL of glacial acetic acid and 0.77 mL of water was added 1.1 g of sodium acetate. The reaction mixture was stirred and heated for 3 h at 95 °C under an atmosphere of nitrogen. After cooling the resulting mixture was poured into ice, basified by careful addition of solid $NaHCO_3$, and extracted with ether. The combined extracts were washed with water and 5% aqueous $NaHCO_3$ and dried over anhydrous Na_2CO_3. Filtration and removal of the solvent gave 450 mg (84%) of a mixture[7] of aldehydes **3** and **4**, showing properties consistent with those reported by Tumlinson:[2] IR (neat) 1681 and 1639 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.96 (s, 6 H, geminal CH_3), 2.24 (t, 2 H, $-CH_2-$ trans to -CHO), 2.50 (s, 2 H, $-CH_2-$ cis to -CHO), 5.92 (d, 1 H, J = 8 Hz, -C=CH-), and 9.98 (d, 1 H, J = 8 Hz, -CHO) were assigned to **3**, while those peaks at 0.93 (s, 6 H geminal CH_3), 2.08 (s, 2 H, $-CH_2-$ trans to -CHO), 2.68 (t, 2 H, $-CH_2-$ cis to -CHO), 5.78 (d, 2 H, J = 8 Hz, -C=CH-), and 10.02 (d, 1 H, J = 8 Hz, -CHO) were assigned to **4**. NMR peaks at 1.2–1.9 were common to both isomers; mol wt 152.1206 (calcd for $C_{10}H_{16}O$: 152.1201).

Preparation of the Isomeric Alcohols (*Z*)-3,3-Dimethyl-$\Delta^{1,\beta}$-cyclohexaneethanol (2) and (*E*)-3,3-Dimethyl-($\Delta^{1,\beta}$-cyclohexaneethanol (9). A mixture of 400 mg of aldehydes **3** and **4** (6:4 ratio) in 20 mL of absolute ethanol and 400 mg of $NaBH_4$ was stirred at ambient temperature for 1 h. The reaction mixture was hydrolyzed with water and extracted with CH_2Cl_2. The combined extracts were washed with water and dried over anhydrous $MgSO_4$. Filtration and removal of the solvent gave the isomeric alcohols **2** and **9** in a quantitative yield, showing properties consistent with those reported by Tumlinson:[2] IR (neat) 3400, 1667, 1075, 1031, 1000 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.90 (s, 6 H, geminal CH_3), 1.92 (s, 2 H, $-CH_2-$ cis to $-CH_2OH$), 2.07 (t, 2 H, $-CH_2-$ trans to $-CH_2OH$), 4.12 (d, 2 H, J = 7 Hz, $-CH_2OH$), and 5.48 (t, 1 H, J = 7 Hz, -C=CH-) were assigned to **2**, while those at 0.87 (s, 6 H, geminal CH_3), 1.89 (s, 2 H, $-CH_2-$ trans to $-CH_2OH$), 2.12 (t, 2 H, $-CH_2-$ cis to $-CH_2OH$), 4.14 (d, 2 H, J = 7 Hz, $-CH_2OH$), and 5.32 (t, 1 H, J = 7 Hz, -C=CH-) were assigned to **9**. NMR peaks at 1.2–1.8 were common to both isomers; mol wt 154.1341 (calcd for $C_{10}H_{18}O$: 154.1357).

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Registry No.—**2**, 26532-23-0; **3**, 26532-24-1; **4**, 26532-25-2; **6**, 2979-19-3; **7**, 65392-27-0; **8**, 65392-28-1; **9**, 30346-27-1; triethyl orthoformate, 122-51-0; ethyl vinyl ether, 109-92-2.

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Cobalt-Catalyzed Oxidation of Isotopically Labeled Cyclohexanone

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A large body of literature exists covering various aspects of metal-catalyzed oxidation of cyclohexanone or cyclohexane to yield predominantly adipic acid.[1-4] We report herein results of studies on cobalt-catalyzed oxidations of isotopically labeled cyclohexanone. Of the numerous by-products formed, glutaric and succinic acids are formed in 10–20% yields. We examined the fate of cyclohexanone labeled at the carbonyl carbon with ^{14}C and with ^{13}C to try to resolve conflicting mechanistic proposals for the formation of glutaric and succinic acids.

The percentage retention of the carbonyl carbon from labeled cyclohexanone in glutaric and succinic acid products was 91% in glutaric acid and 87% in succinic acid as shown in Table I.

The high retention of C-1 from labeled cyclohexanone is not consistent with a proposal that glutaric acid arises by exclusive

Table I. Oxidation of [1-^{14}C]- and [1-^{13}C]Cyclohexanone (K): Percent Retention of C-1 by Glutaric and Succinic Acids

	% retention of C-1		% K	% yields from K		
K	Glutaric/ adipic	Succinic/ adipic	conversion	Adipic	Glutaric	Succinic
[1-^{14}C]	88	82	63	18	5	0.4
[1-^{13}C]	96	84	62	23	4	0.5
[1-^{13}C]	88	94	34	37	8	1.1
Average	91	87				

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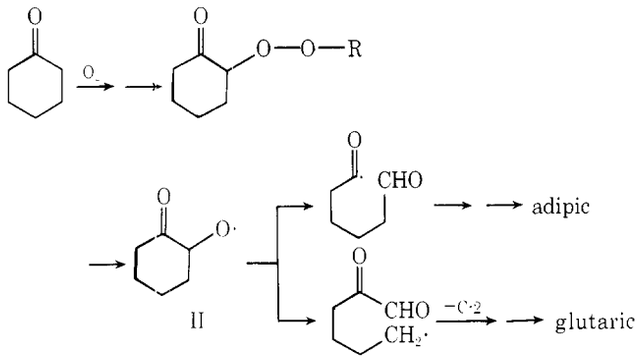
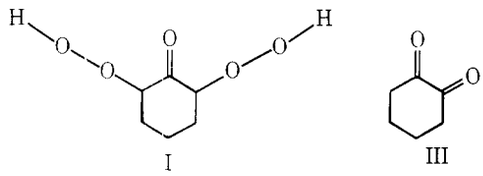


loss of C-1 from an intermediate 2,6-dihydroperoxycyclohexanone compound (I).[5] A more recent proposal that glutaric acid is formed by loss of C-2 from an α-ketooxy radical (II) is consistent with the observed high retention of the labeled carbonyl carbon.[3]

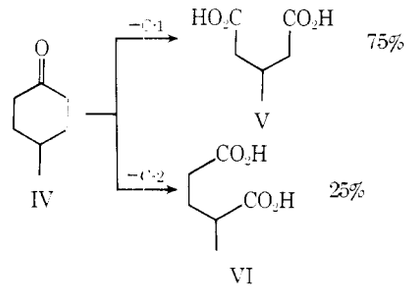
It has been reported that α-ketooxy radicals undergo thermolysis or metal-catalyzed cleavage to generate carboxylic acids in which the carboxyl group is derived from the keto group.[6] It has been proposed that 1,2-cyclohexanedione (III)



is formed during oxidation of cyclohexanone and gives rise to most of the CO and CO_2 evolved.[7] Although 1,2-cyclohexanedione may account for CO and CO_2 generation, it is not a viable intermediate for glutaric or succinic acid formation. Loss of a carbonyl carbon from III would decrease the isotopic enrichment by a factor of 2.

Significant glutaric acid formation from decarboxylation of adipic acid is not consistent with the observed high degree of retention of C-1 from labeled cyclohexanone or with reported carboxylic acid decarboxylation studies.[8,9] The extent to which succinic acid is derived from solvent acetic acid was examined using [1-^{14}C]acetic acid under the oxidation conditions used for labeled cyclohexanone. The conversion of cyclohexanone was 44% with a yield to adipic acid of 27%. Radiometric analysis of isolated succinic acid showed the presence of 0.04 mol of [1-^{14}C]carboxyl groups per mole of succinic acid. Assuming all HO_2C–CH_2· radicals were derived from acetic acid, about 2% of the succinic acid was derived from acetic acid.

The effect of methyl substitution on the extent of loss of C-1 was found to be substantial. Whereas unsubstituted (labeled) cyclohexanone gave glutaric acid with >90% retention of C-1, 4-methylcyclohexanone (IV) gave a 3-methylglutaric (V)/2-methylglutaric (VI) acid ratio of 3:1. The stability of diacid products V and VI to reaction conditions was checked by replacing half of the cyclohexanone in a typical oxidation experiment with equal molar amounts of V and VI. Of the cyclohexanone charged, 34% was converted to adipic acid. The ratio of V/VI in the product was 1.0 within experimental error



based on ^{1}H NMR integrals for the methyl resonances for V (δ 1.05) and VI (δ 1.15). The preponderance of loss of C-1 with methyl substitution may be largely a steric effect.

Experimental Section

All oxidation reactions were carried out in 10-cm^3 stainless steel shaker tubes at 100 °C with 200 psi of O_2 for 10–16 h. A typical starting solution consisted of 5.5 g (91.7 mmol) of acetic acid, 1.05 g (10.7 mmol) of [1-^{14}C]cyclohexanone, and 0.10 g (0.42 mmol) of $Co(OAc)_3$. Gas chromatographic analyses for adipic, glutaric, and succinic acids were carried out on a 12 ft × 0.12 in. stainless steel column of OV-1 at 190 °C following treatment with BSTFA to form trimethylsilyl diesters. [1-^{14}C]Cyclohexanone was commercially available.[10] [1-^{13}C]Cyclohexanone was prepared by carbonylation of bisborinane with ^{13}CO.[11] Products containing ^{14}C were analyzed with a Packard liquid scintillation spectrometer using standard dilution techniques. Each sample was crystallized repeatedly to obtain constant specific activity. Products containing ^{13}C were analyzed by gas chromatography/mass spectroscopic techniques.[12]

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Registry No.—$Co(OAc)_3$, 917-69-1; cyclohexanone, 108-94-1; glutaric acid, 110-94-1; succinic acid, 110-15-6.

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Synthesis of *N*-(4-Azido-2-nitrophenyl)amino-1-alkyl-β-D-glucopyranosides: Photoaffinity Labeling Derivatives of Glucose

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During the course of studies of the mechanism of glucose transport in human erythrocytes, the need arose for derivatives of glucose which could serve as photoaffinity labeling agents.[1,2] Since an integral part of these studies involved the evaluation of reagents in which the distance between the sugar moiety and the photolabile grouping was varied systemati-

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