Selective Formations of Several Carboxylic Acids by Carbonylation in the $SbCl_5$–Liquid Sulfur Dioxide System*

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The carbonylations of *cis*- and *trans*-4-*t*-butyl-1-methylcyclohexanols, *exo*- and *endo*-2-methyl-2-norbornanols and *exo*- and *endo*-2-norbornanols were carried out in $SbCl_5$–liq.SO_2 at −70°. From both the *cis*- and *trans*-4-*t*-butyl-1-methyl-cyclohexanols, *cis*-4-*t*-butyl-1-methylcyclohexanecarboxylic acid was formed exclusively in an excellent yield (over 90%). Both *exo*- and *endo*-2-methyl-2-norbornanols gave only *endo*-2-methyl-*exo*-2-norbornylcarboxylic acid in a high yield. The reason for the stereoselectivity of the reactions was discussed.

A convenient carbonylation of alkyl halides with carbon monoxide at −70 °C in the $SbCl_5$–SO_2 system to give carboxylic acids or esters in good yields and with a high selectivity has been reported in a preceding paper.1) In the present paper we wish to describe the results of the carbonylation of alicyclic alcohols, whose stereochemistries had previously been confirmed, in order to investigate the steric course of the carbonylation in this system along with the mechanism of the reaction. The reactions of *cis*- and *trans*-4-*t*-butyl-1-methylcyclohexanols, *exo*- and *endo*-2-methyl-2-norbornanols and *exo*- and *endo*-2-norbornanols have been carried out. The results thus obtained are gathered in Table 1.

From both *cis*- and *trans*-4-*t*-butyl-1-methylcyclohexanols (I and II), *cis*-4-*t*-butyl-1-methylcyclohexanecarboxylic acid (III) was obtained exclusively in a yield of over 90%. *exo*- and *endo*-2-Methyl-2-norbornanols (IV and V) also gave 2-*endo*-methyl-2-*exo*-norbornanecarboxylic acid (VI) exclusively in a high yield. Furthermore, *exo*- and *endo*-2-norbornanols (VII and VIII) were carbonylated to give only *exo*-norbornane-2-carboxylic acid (IX). The yield of IX from VII is very good (92%), but that of IX from VIII is low (16%). These results seem to be important from the preparative point of view, and also to be suggestive of the reaction mechanism. Whereas the carbonylation reaction of the mixture of I and II with formic acid and sulfuric acid (Koch's method) has been reported to give III (*cis*-carboxylic acid) in a 35% yield along with six other isomeric carboxylic acids,2) III was obtained stereospecifically in the present reaction.

The stereochemistry of the reactions of a number of nucleophiles with 4-*t*-butyl-1-methylcyclohexanol in the presence of acetic acid and sulfuric acid has previously been studied. According to Beeby and Sternhell, the stereoselectivity of the reaction was found to depend upon the size of the attacking nucleophile.2) The stereochemistry of the product is determined by the stability of the oxocarbonium ion (B) and not by the attacking facility of carbon monoxide on the carbonium ion (A), although the attack of carbon monoxide seems to be possible from the equatorial direction because of the lack of 1,3-diaxial interaction. Carbon monoxide, whose steric bulkiness is comparable to that of acetylene,3) is much smaller than the methyl group. The formation of III in the $SbCl_5$–SO_2 system with a high selectivity and a high yield seems to be due to the irreversible formation of 1:1 donor acceptor complex (C) between acyl halide and $SbCl_5$ from B, which is predominantly formed under those reaction conditions. The reaction course is depicted in Chart 1.

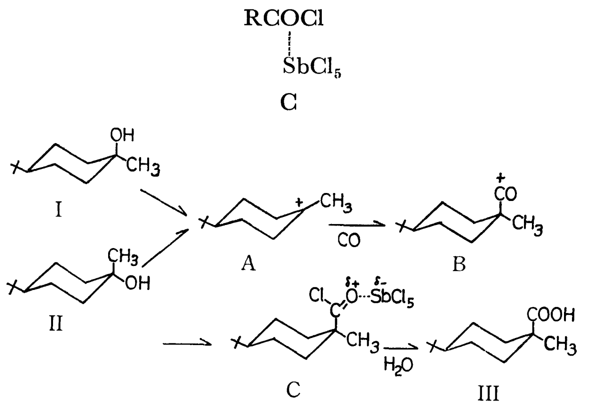

Chart 1.

In the Koch reaction, the formation of olefin is frequently encountered, this gives other side products

Table 1. Carbonylation of alicyclic alcohols in $SbCl_5$–liq. SO_2 at −70 °C

Alcohol	Product (yield %)
cis-4-*t*-Butyl-1-methylcyclohexanol (I)	*cis*-4-*t*-Butyl-1-methylcyclohexanecarboxylic acid (III), (94)
trans-4-*t*-Butyl-1-methylcyclohexanol (II)	III, (90)
exo-2-Methyl-2-norbornanol (IV)	2-*endo*-Methyl-2-*exo*-norbornanecarboxylic acid (VI), (96)
endo-2-Methyl-2-norbornanol (V)	VI, (85)
exo-2-Norbornanol (VII)	*exo*-Norbornane-2-carboxylic acid, (IX), (92)
endo-2-Norbornanol (VIII)	IX, (16)

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* Carbonylation in Liq. SO_2, part II: Preceding Paper, Ref. 1.

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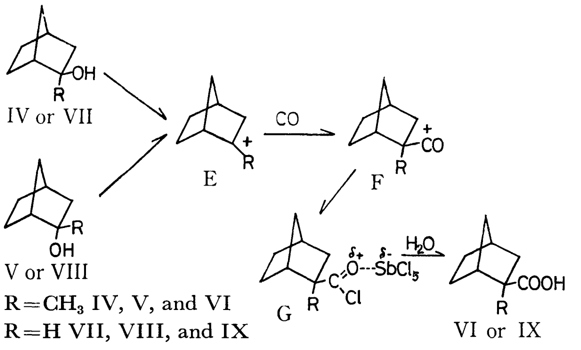

Chart 2.

in the reaction.[4] In the present reaction, the formation of olefin, polymerization, and oxidation were depressed for the reason described before.

The selective formations of *endo*-2-methyl-*exo*-2-norbornanecarboxylic acid from *exo*- and *endo*-2-methyl-2-norbornanols and *exo*-2-norbornanecarboxylic acid from *exo*- and *endo*-2-norbornanols are interesting. It was clarified by Hogeveen and Roobeek[5] that the formation of F in Koch's reaction is kinetically controlled, while, under thermodynamically-controlled conditions, both *exo*- and *endo*-norbornyl oxocarbonium ions were formed to the same extent, the ratio of the *exo*- and *endo*-norbornanecarboxylic acids produced being 51 to 49.

These results suggest that, in our reaction, the same carbonium ion was formed from epimers and was subsequently carbonylated by the stereospecifical *exo* attack of CO on an oxocarbonium ion, followed by the formation of a 1: 1 donor-acceptor complex[6] of acyl halide and $SbCl_5$.

The *exo* attack of the nucleophilic reagent on norbornyl and 2-methylnorbornyl cations in kinetically-controlled reactions, has been well confirmed.[7] The present results seem to be consistent with these facts and with the formation of the norbornyl cation and the 2-methylnorbornyl cation, followed by the attack of carbon monoxide from the *exo* direction.

In the carbonylation of *endo*-2-norbornanol (VIII), the conversion to the product, IX, was very low, the starting norbornanol was almost all recovered, and no olefinic or polymeric material was found in the reaction mixture. These results suggest that the formation of the carbonium ion is the rate-determining step in this reaction and that the attack of carbon monoxide on this carbonium ion is a very fast step, as has already been indicated by Hogeveen.[5]

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Experimental

Materials. *cis*-4-*t*-Butyl-1-methylcyclohexanol (I) was obtained by the oxymercuration of 4-*t*-butyl-1-methylcyclohexene.[8] *trans*-4-*t*-Butyl-1-methylcyclohexanol (II) was prepared by the method of Corey.[9] *exo*-2-Methyl-2-norbornanol (IV) was obtained by the oxymercuration and reduction of 2-methylnorbornene-2.[10] *endo*-2-Methyl-2-norbornanol (V) was obtained by the reaction of 2-norbornanone with methylmagnesium iodide.[11] By the hydrolysis of *exo*-2-norbornyl formate, *exo*-2-norbornanol (VII) was obtained.[10] *endo*-2-Norbornanol (VIII) was prepared by the reduction of 2-norbornanone with lithium aluminum hydride.[12]

General Procedure of Carbonylation. Into a mixture of 20 g (0.07 mol) of $SbCl_5$ and 50 ml of liq. SO_2, an alcohol in 20 ml of dichloromethane was dropped at -70 °C over a thirty-minute period while a current of carbon monoxide gas was being bubbled into the flask at a velocity of 70 ml per minute, after which the reaction was continued for an additional thirty minutes. Then the reaction mixture was poured into ice-cold aqueous sodium hydroxide, and the neutral products were extracted by ether. Then the acidic products were extracted with ether after the water layer had been acidified with aqueous hydrogen chloride. After the evaporation of the ether, the product was characterized by NMR, infrared, and mass spectroscopies.

The Reaction of I and II. *cis*-4-*t*-Butyl-1-methylcyclohexanol, (I) (1.70 g, 0.01 mol), was allowed to react with carbon monoxide following the general procedure. After the evaporation of the ether, 1.86 g of a solid (III) was obtained. III was identified as 4-*t*-butyl-1-methylcyclohexanecarboxylic acid by comparing it with the physical data of an authentic sample;[2] mp 132—133 °C (lit,[2] 132—133 °C). The crude product was reduced by lithium aluminum hydride and was analyzed by glc; the glc showed the formation of only *cis*-4-*t*-butyl-1-methylcyclohexylcarbinol.[2]

By the reaction of II (1.70 g, 0.01 mol), III was obtained in a 90% yield.

The Reaction of IV and V. From *exo*-2-methyl-2-norbornanol (IV) (1.26 g, 0.01 mol), 1.48 g (96% yield) of 2-*endo*-methyl-2-*exo*-norbornanecarboxylic acid were obtained; mp 50—51 °C (lit,[13] 50—52 °C). The physical data were identical with those of an authentic sample.[13]

The selective formation of VI was clarified by the glc analysis of the reduction products with lithium aluminum hydride. From V, VI was obtained exclusively in an 85% yield.

The Reaction of VII and VIII. By the reaction of VII (1.12 g, 0.01 mol) under these reaction conditions, 1.29 g (92% yield) of 2-*exo*-norbornanecarboxylic acid (IX) was obtained; mp 52—53 °C (lit,[14] 52—53 °C).

In the reaction of *endo*-2-norbornanol (VIII), IX was obtained as the acidic product in a 16% yield, and from the neutral part 80% of the starting material, VIII, was recovered.

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