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Organic Sulfur Compound. X. The Mechanism of the Carboxylic Ester Formation from Carboxylic Sulfurous Anhydrides

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Sodium benzoate-^{18}O reacts with methyl chlorosulfite to give methyl benzoate-^{18}O in a low yield; the excess ^{18}O content has been found to be exactly one-half of that in the starting benzoic acid. Another reaction of the labeled benzoic acid with phenyl chlorosulfite gives phenyl benzoate-^{18}O; its excess ^{18}O atom% is also one-half of that of benzoic acid. Both reactions are considered to proceed by way of the intermediate formation of the benzoic sulfurous mixed anhydrides, the decomposition of which by acyl-oxygen splitting affords the carboxylic esters labeled only in the carbonyl group.

The formation of the mixed anhydride (I) of the carboxylic acid and the sulfurous acid monoester (reaction 1) and its thermal decomposition at a relatively low temperature to give the carboxylic anhydride and the sulfurous acid diester (reaction 2) have been described in a preceding paper.[1] When the reaction mixture of the carboxylic acid salt with the chlorosulfite ester was heated at a high temperature until the evolution of sulfur dioxide was completed, the carboxylic ester has been reported to be formed in a good yield, probably by means of the intermediate formation of I (reaction 3):[2,3]

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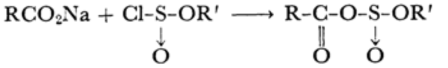
1) Part II of this series. M. Kobayashi and A. Yamamoto, This Bulletin, **39**, 961 (1966).

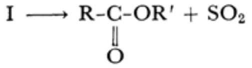
2) P. Carré and D. Libermann, *Bull. soc. chim. France,* [4] **53**, 1050 (1933).

3) M. S. Newman and W. S. Fones, *J. Am. Chem. Soc.,* **69**, 1046 (1947).



$$\mathrm{RCO_2Na + Cl{-}\underset{\substack{\downarrow\\ O}}{S}{-}OR' \longrightarrow R{-}\underset{\substack{\|\\ O}}{C}{-}O{-}\underset{\substack{\downarrow\\ O}}{S}{-}OR'} \tag{1}$$

$$\mathrm{I \longrightarrow {}^1/_2(RCO)_2O + {}^1/_2(R'O)_2SO + {}^1/_2SO_2} \tag{2}$$

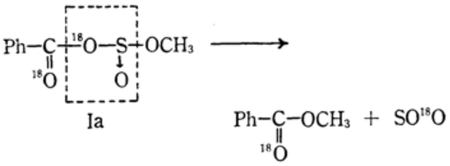


$$\mathrm{I \longrightarrow R{-}\underset{\substack{\|\\ O}}{C}{-}OR' + SO_2} \tag{3}$$

It has not been established which bond in I is broken in the last reaction. Moreover, there is another possible course by which the carboxylic ester is formed from the salt of the carboxylic acid and the chlorosulfite ester—namely, a secondary reaction between two primary products of the decomposition reaction 2 of I, the carboxylic anhydride and sulfurous acid diester, — besides the direct decomposition of I (reaction 3) to the carboxylic ester. In order to obtain information about these points, the present investigation, using the ^{18}O-labeling method, was carried out.

Results and Discussion

The ^{18}O labeled sodium benzoate and methyl chlorosulfite were mixed, and the resulting jelly-like mixture was heated in an oil bath for 4 hr., until the evolution of sulfur dioxide had ceased. The products were then spearated by fractional distillation into benzoic anhydride (50% yield), dimethyl sulfite (25% yield) and methyl benzoate (about a 5% yield). The excess ^{18}O atom percentage of methyl benzoate was found to be exactly a half of that of the starting sodium benzoate. This reaction may be formulated as follows:

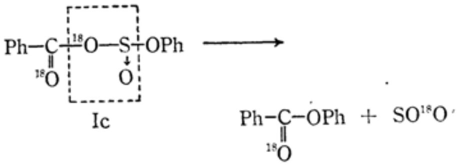


$$\mathrm{Ph{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}{}^{18}O{-}\underset{\substack{\downarrow\\ O}}{S}{-}OCH_3 \longrightarrow Ph{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}OCH_3 + SO^{18}O} \tag{4}$$

Ia

Ethyl benzoyloxysulfinate Ib, which is a close analog of the methyl ester Ia postulated above, had previously been obtained in a solution or in the sirupy liquid state.1) This compound has now been found to be distillable in a high vacuum with only slight decomposition. The infrared spectrum of the distillated sample was almost the same as that already reported.1)

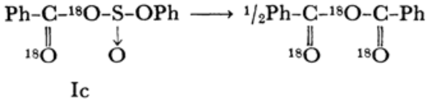
Equimolar amounts of the labeled benzoic acid and phenyl chlorosulfite were treated with triethylamine in ether, whereas triethylamine hydrochloride was precipitated quantitatively. The filtrate exhibited strong infrared absorption bands at 1729 cm^{-1} (C=O) and 1230 cm^{-1} (S-O), suggesting the formation of phenyl benzoyloxysulfinate Ic. The evaporation of ether in a vacuum gave a colorless residue; this residue was pyrolyzed at 90—140°C for 2 hr., until no more sulfur dioxide evolved. When the product mixture was treated with aniline in carbon tetrachloride, 55 mol.% of benzanilide was precipitated. The filtrate was then evaporated, and the remaining oil was chromatographed to give 20 mol.% of phenyl benzoate. Its excess ^{18}O atom% was again almost one-half of that in the original benzoic acid. Consequently, the decomposition of the intermediate Ic may be considered to proceed by the acyl-oxygen splitting shown below:



$$\mathrm{Ph{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}{}^{18}O{-}\underset{\substack{\downarrow\\ O}}{S}{-}OPh \longrightarrow Ph{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}OPh + SO^{18}O} \tag{5}$$

Ic

The ^{18}O atom% of benzanilide should be the same as that of the carbonyl group of benzoic anhydride, which in turn may be expected to be the same as that in the original benzoic acid, provided this anhydride was formed straightforward, by disproportionation (6):



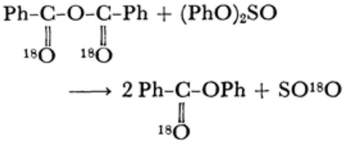
$$\mathrm{Ph{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}{}^{18}O{-}\underset{\substack{\downarrow\\ O}}{S}{-}OPh \longrightarrow {}^1/_2Ph{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}{}^{18}O{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}Ph}$$

Ic

$$\mathrm{+\ {}^1/_2(PhO)_2SO + {}^1/_2SO^{18}O} \tag{6}$$

Actually, the ^{18}O atom % of benzanilide was found to be definitely lower than that of benzoic acid. This suggests that some kind of discrimination of the oxygen atoms must occur in the mixed anhydride, Ic.

If the ^{18}O atom% of the carbonyl group of benzoic anhydride could be postulated to be the same as that of benzanilide (1.29%), the ^{18}O atom % of phenyl benzoate, which would be formed by the interaction of two primary products (benzoic anhydride and diphenyl sulfite) in the reaction 7, as has been pointed out above, should be 0.75%:



$$\mathrm{Ph{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}O{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}Ph + (PhO)_2SO \longrightarrow 2\,Ph{-}\underset{\substack{\|\\ ^{18}O}}{C}{-}OPh + SO^{18}O} \tag{7}$$

(the ether oxygen atom of benzoic anhydride may contain ^{18}O. In the reaction 7, Ph–O bond is assumed to be reserved.)

Actually, the value found (0.98 atom%) was much higher than that, and it coincided rather well with the figure calculated on the basis of the reaction 5. Therefore, the carboxylic ester may be considered to be formed by the direct decomposition of the mixed anhydride Ic, not by a secondary reaction such as 7, at least not in this case.

Experimental

The Preparation of Benzoic Acid-^{18}O.—A mixture of 25 g. of benzotrichloride and 10 g. of $H_2{}^{18}O$

(1.52 atom%) was refluxed for 15 hr., protected against atmospheric moisture. The resultant crystalline mass was warmed under reduced pressure in a water bath for 2 hr. in order to expel the hydrogen chloride formed and excess water. The residue was dissolved in a solution of 8 g. of sodium hydroxide in 50 ml. of water and concentrated. The sodium benzoate thus separated was recrystallized once from the distilled water and dried in a vacuum for 2 hr. at 100°C. The white mass was powdered finely and dried once more in a vacuum at 100°C for a few hours to give about 15 g. of sodium benzoate-^{18}O (first crop). The concentration of the mother liquid gave another 9 g. of the same salt (2nd crop), which was dissolved in water and acidified with diluted hydrochloric acid to give 6 g. of benzoic acid-^{18}O. The ^{18}O atom% of the first crop was 1.49%.

Methyl Chlorosulfite.—To 40 g. of thionyl chloride 10 g. of anhydrous methanol was slowly added; the mixture was left at room temperature for several days. Distillation under reduced pressure gave 24 g. of a fraction boiling at 35—37°C/60 mmHg.

The Reaction of the Labeled Sodium Benzoate with Methyl Chlorosulfite.—To 10.0 g. of sodium benzoate-^{18}O (first crop) 16 g. of methyl chlorosulfite (2 mol.) was added, whereupon the exothermic reaction occurred. The milky reaction mixture was then heated in an oil bath at 110—130°C for 2 hr., during which time a vigorous evolution of sulfur dioxide was observed. The residue was refluxed for 2 hr., while the bath temperature was slowly raised to 190°C. The cooled reaction mixture was treated with ether and water; the ether layer was separated, washed with a sodium hydrogen carbonate solution, and dried over magnesium sulfate, and finally the solvent was removed in a vacuum. The residue was repeatedly fractionally distilled under reduced pressure to give 1 g. of dimethyl sulfite (b. p. 40—45°C/25 mmHg), 0.5 g. of methyl benzoate (the purity was checked by the infrared spectrum), and about 4 g. of benzoic anhydride. The acidification of the alkaline washing gave 0.8 g. of the unchanged benzoic acid. The ^{18}O atom% of methyl benzoate was 0.83%. (The calculated value on the basis of the formula 4 is 0.85%.)

The Reaction of Benzoic Acid-^{18}O with Phenyl Chlorosulfite.—To a solution of 3.0 g. of benzoic acid-^{18}O (^{18}O: 1.65 atom%) and 4.4 g. of phenyl chlorosulfite (equimolar) in 55 ml. of anhydrous ether, 2.5 g. of triethylamine in 10 ml. of ether was added, whereupon the reaction started at once, forming a white crystalline precipitate. After a half hour, the mixture was filtered; this precipitate was recrystallized from ethanol-ether, and identified by means its infrared spectrum as triethylamine hydrochloride (its yield of the crude state was almost the theoretical). The ether filtrate of this salt exhibited infrared absorption at 1729, 1590, 1230, 770, 710, and 690 cm^{-1} (the 1500—1300, and 1200—1000 cm^{-1} regions could not be measured because of the strong absorption of ether). No absorption of benzoic acid at 1690 cm^{-1} was observed. Since phenyl chlorosulfite has a strong absorption at 1228 cm^{-1} and diphenyl sulfite, at 1230 cm^{-1}, the 1230 cm^{-1} band of the product may be attributed to the S–O stretching vibration. Ether was expelled from this solution on a water bath (no sulfur dioxide evolution was observed), and the residue was heated in an oil bath at 80°C in the beginning and then at 140°C in the last stage of the reaction. During the last stage sulfur dioxide evolved vigorously. Finally the oily residue was treated with water and ether, and the ether layer was washed with alkali, dried, and evaporated, leaving about 4 g. of the colorless oil. Since its infrared spectrum indicated the presence of a large amount of benzoic anhydride, the oil was dissolved in carbon tetrachloride and treated with 3 g. of aniline. The separated crystals (3.2 g.) were washed with water and recrystallized from ethanol to give 1.3 g. of benzanilide (identified by its infrared spectrum and m. p.). The carbon tetrachloride filtrate was washed with a sodium hydrogen carbonate solution, water, and diluted hydrochloric acid successively, dried, and evaporated to give 3 g. of a colorless sirup. The chromatography of this sirup on alumina with benzene gave 1.0 g. of phenyl benzoate-^{18}O, m. p. 64°C. The ^{18}O atom% of this specimen was 0.98%. (The value calculated on the basis of the formula 5 was 0.93%.)

Ethyl Benzoyloxysulfinate.—To 5.5 g. of dried sodium benzoate, 7.0 g. of ethyl chlorosulfite was added, and the reaction mixture was vacuum distilled. A colorless liquid was obtained at 85°C/0.2 mmHg; this liquid contained a slight amount of the leaflet of benzoic acid. The infrared spectrum of this ester was almost superimposable upon that reported in the preceding paper.1) The formation of some benzoyl chloride was noticed in a low-boiling fraction.

Ib: 84.43 mg.; $BaSO_4$: 78.94 mg.

Found: S, 12.8%. Calcd. for $C_9H_{10}O_4S$: 14.9%.