

solid crystallized from methyl alcohol in small prisms and melted at 110°.

Anal. Calcd. for $C_{21}H_{23}O_2$: C, 86.3; H, 6.5. Found: C, 86.3; H, 6.6.

This solid is evidently a benzoate because cold methyl alcoholic sodium hydroxide hydrolyzes it rapidly to mesityl phenyl propiophenone. The yield was about 50%.

α -Mesityl- γ,γ -diphenyl Propenol Peroxide, VII.—To a solution of phenylmagnesium bromide containing 1.9 g. of magnesium was added 10 g. of benzalaceto mesitylene. The mixture was boiled for fifteen minutes, then decomposed with iced hydrochloric acid. The ethereal layer was diluted with about five times its volume of petroleum ether and washed thrice with ice water. A rapid stream of oxygen was then passed through the moist solution. It gradually caused the precipitation of a solid which separated in microscopic needles. The solid was purified by solution in ether and reprecipitation with petroleum ether. The yield was 9 g.

Anal. Calcd. for $C_{24}H_{24}O_3$: C, 80.1; H, 6.7. Found: C, 80.6; H, 6.5.

In a capillary tube the peroxide melts quietly with decomposition at 116–117°. Heated in larger quantity on a spatula it decomposes with a flash, one of the decomposition products being mesitylene carbonic acid. Like other peroxides of this type it liberates iodine from alcoholic solutions of iodides.

Summary

A study of the magnesium halide derivatives of a series of related mesitylenic ketones showed that the mesityl group in some manner decreases the speed of the processes represented by $>C=C-R \rightleftharpoons >CH-C-R$. It also showed that

$$\begin{array}{ccc} & \text{OH} & \text{O} \\ & | & || \\ & \text{C} & \text{C} \\ & | & | \\ & \text{R} & \text{R} \end{array}$$

there is a certain degree of correlation between the complexity of the hydrocarbon residues surrounding a carbonyl group, the stability of the enolic form and the mode of acylation.

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Some Derivatives of Beta-Sulfopropionic Acid¹

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The original point of interest which led to the choice of β -sulfopropionic acid as a subject for study, was the fact that it is the aliphatic analog of *o*-sulfobenzoic acid, the imide of which is the well-known sugar substitute, saccharin. While the latter acid has been the subject of intensive and detailed research, our knowledge concerning the former is very meager and incomplete. The purpose of this paper is to present the results of a study of a number of the simpler derivatives of this interesting aliphatic sulfonic acid.

β -Sulfopropionic acid was originally described by Rosenthal² in 1886. He also prepared a large number of the salts, the ethyl ester, and an impure acid chloride, to which he assigned the formula $\begin{array}{c} \text{CHCl-COCl} \\ | \\ \text{CH}_2\text{SO}_2\text{Cl} \end{array}$ on the basis of rather unsatisfactory evidence. His work includes practically all that is known about the compound or its derivatives, although certain of them have been mentioned indirectly by Kohler³ and others.

In the present work, barium β -sulfopropionate

(1) This paper has been abstracted from the Doctorate Thesis of Hugh W. Sigmon, and the Master's Thesis of David H. Wilcox, Jr., presented to the Graduate School of Arts and Sciences of Duke University in 1935 and 1932, respectively.

(2) Rosenthal, *Ann.*, **233**, 15 (1886).

(3) Kohler, *Am. Chem. J.*, **19**, 732 (1897).

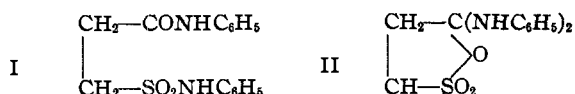
was prepared from β -iodopropionic acid, and subsequently converted into the silver salt, which, in turn, was treated with the appropriate alkyl halides to form the corresponding neutral methyl-, ethyl-, *n*-propyl- and *n*-butyl esters. These were colorless liquids at room temperature, crystallized from ether at low temperatures and melted at 17, 4, -7 and -25° (all $\pm 1^\circ$), respectively. The methyl ester boiled with slight decomposition at 132–3° at 1 mm., and the others could not be distilled.

In the hope of obtaining a solid ester, the silver salt was treated with benzyl bromide, benzyl iodide and phenacyl bromide, but without results. Phenylethyl iodide, however, reacted normally, yielding the neutral phenylethyl ester in white needles, melting at 59°. This ester, on saponification with barium hydroxide, yielded the barium salt of the acid, in 73% yield, apparently identical, under the microscope, with the corresponding salt obtained from β -iodopropionic acid.

When the dry potassium salt of the acid, in benzene suspension, was treated with phosphorus pentachloride, it yielded, ultimately, a light colored oil, thermally unstable even at 0°, which, when crystallized from ether at low temperatures

deposited as a white solid, melting at -9° ($\pm 1^{\circ}$). It was undoubtedly the acid chloride, since on hydrolysis with barium hydroxide solution it regenerated the original barium salt in 77% yield, and on treatment with phenylethyl alcohol it formed the phenylethyl ester, melting at 58° although in small yield.

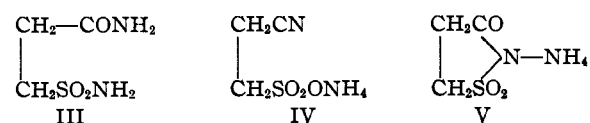
This chloride, when treated in benzene solution with aniline, gave rise to the corresponding dianilide, melting at 161° . This compound presumably had the structure I rather than II



because it was similar in properties to the well-known symmetrical dianilide of *o*-sulfobenzoic acid, and not to the corresponding unsymmetrical isomer. On hydrolysis with sulfuric acid, it formed the free sulfonic acid, recovered in 69% yield as the barium salt. The fact that the anilide contained no chlorine indicated that the acid chloride from which it was derived was not substituted in the carbon chain, contrary to Rosenthal.²

When anhydrous ammonia gas was passed through a solution of the chloride in benzene, a white solid was precipitated quantitatively. After removing the inorganic salts, the product was crystallized from alcohol in white prisms melting at $164\text{--}168^{\circ}$ with some decomposition.

On theoretical considerations this product could have three reasonably possible configurations, representing it as β -sulfopropionidamide III, ammonium β -cyanoethyl sulfonate IV or ammonium β -sulfopropionimide V.



Formula III was eliminated readily since the compound had definite salt-like properties, being insoluble in organic solvents, highly soluble in water and having a fairly high melting point. In addition, on analysis by the Van Slyke method for amide and amino nitrogen, it evolved less than one-fourth of its total nitrogen content. The structure IV, derived from the possible unsymmetrical acid chloride, seemed improbable, especially since the compound could be converted readily into a corresponding barium salt in almost quantitative yield, while Remsen and Kars-

lake⁴ have found that ammonium *o*-cyanobenzene sulfonate tended to undergo hydrolysis under these conditions. Consequently, the product has been assigned provisionally the structure V, making its formation strictly analogous to that of the ammonium salt of saccharin under comparable conditions.

The salt V, dissolved in water, yielded no precipitate with acids, and was not sweet. When the corresponding barium salt, mentioned above, was treated in aqueous solution with one equivalent of sulfuric acid, the free imide was not produced. Instead, hydrolysis occurred, with the formation in part of the diammonium salt of β -sulfopropionic acid.

An effort was made, also, to obtain the free imide by the pyrolysis of pure ammonium β -sulfopropionate. When this salt was heated for forty to ninety hours at 111° and 3–4 mm. it lost 0.8–1.0 mole of ammonia per mole of sample, yielding a solid product having the composition of the corresponding acid ammonium salt, which on treatment with barium hydroxide regenerated the ordinary barium salt. However, when the temperature of the pyrolysis was increased to 184° , a slow but complete disruption of the molecule took place, and the desired imide was not formed.

Experimental Part

Barium β -Sulfopropionate.—This salt was prepared according to the method of Rosenthal,² using a 20% excess of fresh ammonium sulfite and separated from water as colorless plates, in 60–70% yield after dehydration at $150\text{--}170^{\circ}$.

Silver Salt.—A sample of 15.5 g. of the anhydrous barium salt was dissolved in 500 cc. of water and one equivalent of sulfuric acid added. After filtration, 13.7 g. of silver oxide (10% excess) was added, and the mixture again filtered. On cooling and subsequent concentration the silver salt separated in gray crystals, weighing 15.7 g., which is 78%. A sample dried over calcium chloride did not lose weight when further dried over phosphorus pentoxide for forty hours at 2 mm., and was therefore anhydrous, contrary to Rosenthal.²

Anal. Calcd. for $\text{C}_3\text{H}_4\text{O}_5\text{SAg}_2$: Ag, 58.7. Found: Ag, 58.7, 58.6.

Methyl Ester.—Exactly 15.0 g. of the silver salt was heated with 15 cc. of methyl iodide in a sealed tube for six and one-half hours at 100° . The product was diluted with ether, filtered, extracted with 1% sodium sulfite solution, dried over anhydrous sodium sulfate and the solvent removed under reduced pressure at room temperature, leaving 5.77 g. of a yellow oil, which is 77%. The crude ester was crystallized twice from 15-cc. portions of

(4) Remsen and Karslake, *Am. Chem. J.*, **18**, 819 (1896).

dry ether at about -65° (solid carbon dioxide-ether bath). The mother liquor in each case was withdrawn by means of a small suction tube with a cloth filter. The product separated in white crystals, which were freed from ether by allowing them to melt, and aspirating the colorless liquid with dry air for one hour at 50° and 1 mm. The pure ester boiled at $132-133^{\circ}$ at 1 mm., with slight decomposition, and melted at 17° .

Other Esters.—The ethyl ester was synthesized by refluxing the silver salt with ethyl iodide. It was analyzed by Rosenthal² but he did not report the melting point. The *n*-propyl ester formed readily on refluxing the silver salt with *n*-propyl iodide, but in the case of the *n*-butyl ester the salt was heated with the corresponding halide for seven hours at 100° . The phenylethyl ester was made by heating the salt with phenylethyl iodide for ten hours at 100° . The halide in this case was prepared by refluxing 20 g. of phenylethyl bromide with an equal weight of sodium iodide in 100 cc. of acetone for four hours. After filtration and rectification the iodide was obtained in 71% yield, b. p. $117-121^{\circ}$. The phenylethyl ester, being solid at room temperature, was crystallized from ethanol.

When 0.20 g. of the phenylethyl ester was refluxed with a mixture of 2 cc. of sulfuric acid and 25 cc. of water for three and one-half hours it was hydrolyzed readily, and the free acid recovered as the barium salt, in 73% yield, identical with that obtained from β -iodopropionic acid.

TABLE I
ANALYTICAL AND OTHER DATA FOR THE ESTERS OF β -SULFOPROPIONIC ACID

Ester	Crude yield, %	M. p., $^{\circ}$ C.	Calculated		Found			
			S, %	Mol. wt.	S, %	S, %	Mol. wt. (K, 5.12)	Mol. wt. (K, 5.12)
Methyl	78	17	17.6	182	17.6	17.7	188	194
Ethyl	78	4
<i>n</i> -Propyl	86	-7	13.4	238	13.4	13.4	236	235
<i>n</i> -Butyl	96	-25	12.0	266	11.9	12.1	266	262
Phenylethyl	64	59	8.9	362	9.0	9.0	366	366

The Acid Chloride.—Pure potassium β -sulfopropionate was prepared, in quantitative yield, by treating the barium salt in aqueous solution, with an equivalent of potassium sulfate. It was dried for several hours at $150-170^{\circ}$. Then 47 g. of the potassium salt was suspended in 250 cc. of dry benzene, in a 1-liter 3-necked flask equipped with a mechanical stirrer, and 85 g. of phosphorus pentachloride (2 moles) added all at once. Reaction set in immediately, and the mixture was stirred and refluxed for two hours after which it was filtered by suction through asbestos. The light straw colored solution was then extracted at room temperature with 2-liters of water in 200-cc. portions, which freed it completely from phosphorus compounds (molybdate test). After drying the mixture with anhydrous sodium sulfate, the solvent was removed, first by aspirating with dry carbon dioxide at 15 mm., finally for one-half hour at 1-2 mm., at room temperature. There remained a light pink oil, together with a small quantity of white solid, weighing in all 15.5 g., which is 39%. The solid was removed by filtration through a cotton plug, using a suction tube, and the liquid product kept frozen at -65° , or in solution, as it decomposed thermally on standing at room temperature evolving hydrogen chloride. The chloride was then dissolved

in 50 cc. of dry ether, in an atmosphere of dry carbon dioxide, cooled to -65° , and seeded, when a small crop of crystals separated, which were removed and discarded, this process being repeated five times. Then the solvent was evaporated under reduced pressure at 0° , and the remaining oil crystallized twice from 20-cc. portions of dry ether, in a carbon dioxide atmosphere at -65° . Finally the white solid was allowed to melt, and the solvent removed completely by keeping the mixture at 2 mm. and -5° for three and one-half hours. A U-tube filled with sulfuric acid, and placed in the train, did not increase in weight after the first two hours. The final product was a light colored oil, which on cooling froze to a white solid, melting at -9° ($\pm 1^{\circ}$).

In spite of this extremely careful purification, the chloride still retained a little of the free acid, presumably, as chlorine and sulfur analyses showed it to be only about 92% pure. However, when a sample was hydrolyzed by boiling for ten minutes with 7% $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ solution, the original barium salt was recovered readily in 77% yield. Also, when the chloride was treated with an excess of phenylethyl alcohol, which was later distilled off at $101-104^{\circ}$ at 2 mm., the residue solidified on cooling. The solid was crystallized from ethanol and separated as white needles melting at 58° . When these were mixed with an authentic sample of the phenylethyl ester, the melting point was not depressed. The yield was 17% of the theoretical.

The Dianilide.—A sample of crude acid chloride, weighing 5.8 g., was dissolved in 100 cc. of dry benzene, and cooled in an ice-bath. Then a solution of 12 cc. of aniline in 25 cc. of benzene was added, drop by drop, with shaking, which caused the separation of a pasty solid. The liquid was decanted and evaporated, but contained no residue. The solid product was extracted with 1% hydrochloric acid solution, until the extract failed to give a test for aniline. Then it was dissolved in 25 cc. of boiling 50% ethanol, and separated on cooling as white crystals which contained no chlorine, weighing 2.1 g., which is 22% of the theoretical. After recrystallization twice from 10-cc. portions of 50% ethanol, it deposited as white leaflets, which melted sharply at 161° .

Anal. Calcd. for $\text{C}_{15}\text{H}_{16}\text{O}_3\text{N}_2\text{S}$: S, 10.5; N, 9.2; mol. wt., 304. Found: S, 10.4, 10.6; N, 9.2, 9.1; mol. wt., 316.

On refluxing the anilide with a mixture of 2 cc. of sulfuric acid and 25 cc. of water for five hours it was hydrolyzed, and the acid was recovered as the original barium salt in 69% yield.

Ammonium β -Sulfopropionimide.—A sample of the phosphorus-free acid chloride weighing 15.5 g. was dissolved in 200 cc. of dry benzene, cooled in an ice-bath and saturated with dry ammonia gas. A white solid separated, which dissolved completely when the mixture was subsequently extracted with 150 cc. of water. The benzene layer, on evaporation, left no appreciable residue. Then the aqueous solution was triturated, in portions, with solid silver carbonate, until it was entirely free from Cl^- . After the excess silver carbonate and the silver chloride had been removed, the filtrate was saturated with hydrogen sulfide and filtered again. The final filtrate was evaporated to dryness on a water-bath under reduced pressure, and left a yellow viscous oil, which solidified

completely on cooling. The solid, which contained neither silver nor chlorine, was crystallized from 50 cc. of ethanol, and separated in white prisms, melting at about 162°, and weighing 6.64 g., which is 53%. After many crystallizations, the melting point varied irregularly from 164–168°, due to decomposition, as the compound evolved some ammonia even at 110°.

Anal. Calcd. for $C_3H_8O_3N_2S$: S, 21.0; N, 18.4. Found: S, 21.0, 21.0; N, 18.4, 18.3.

It should be mentioned that repeated crystallization of the original precipitate from dry *n*-propyl alcohol until the product was free from chlorine yielded the same compound, although in much less yield.

Barium Salt of the Imide.—A sample of the ammonium salt weighing 3.47 g. was dissolved in 100 cc. of water and treated with barium hydroxide solution, equivalent to half the nitrogen contained in the sample. No precipitate was formed, so the mixture was evaporated to dryness under reduced pressure. The white residue was crystallized from 20 cc. of dilute ethanol, and separated as white needles, in practically quantitative yield. After one more crystallization it was quite pure.

Anal. Calcd. for $C_3H_8O_3S_2N_2Ba$: Ba, 33.7; N, 6.9. Found: Ba, 33.8, 33.5; N, 6.9, 6.9.

When this barium salt in aqueous solution was treated with one equivalent of ammonium sulfate, ammonium β -sulfopropionimide was regenerated in 63% yield, melting at 167–168°. On admixture with the original ammonium salt, the melting point was not depressed.

Attempt to Prepare the Free Imide.—A solution of 4.5 g. of barium β -sulfopropionimide in 25 cc. of water was treated with the calculated quantity of dilute sulfuric acid. The filtrate was evaporated to dryness under reduced pressure, and left a solid residue, which on crystallization three times from methanol separated as white crystals which contracted at 170°, and melted at 175–176°. The compound contained neither barium nor chlorine, and seemed to be the diammonium salt of β -sulfopropionic acid.

Anal. Calcd. for $C_3H_{12}O_6N_4S$: N, 14.9. Found: N, 14.7.

Pyrolysis of Diammonium β -Sulfopropionate.—This compound was prepared by treating an aqueous solution of the barium salt with one equivalent of ammonium sulfate. After filtration, the solution was evaporated to a small volume, during which time it gave off ammonia. Finally the mixture was saturated with ammonia gas, and the crystals which deposited on standing in the cold, filtered off, washed with ethanol and dried to constant weight over sulfuric acid, at 2 mm. The yield was 68–70%, and,

under these conditions, was anhydrous and not very hygroscopic.

Anal. Calcd. for $C_3H_{12}O_6N_4S$: S, 17.0; N, 14.9. Found: S, 16.9, 17.2; N, 15.0, 14.6.

For the pyrolysis, a weighed sample of the salt was placed in a boat contained in an oven tube so arranged that it could be entirely surrounded by the vapors of boiling toluene (111°). It was connected to a train consisting of a U-tube filled with solid potassium hydroxide, and two U-tubes containing glass beads and sulfuric acid. The pressure in the system was reduced to 3–4 mm., the sample heated to 111°, and its loss in weight observed, as well as the corresponding gain in the absorption tubes. Blank runs were made each time, and adequate corrections applied. The potassium hydroxide gained very little weight under these conditions. The results are expressed in the table below.

TABLE II

PYROLYSIS OF DIAMMONIUM β -SULFOPROPIONATE AT 111°

No.....	1	2	
Time, hours.....	40	90	
Moles NH ₃ per mole sample {	Evolved.....	0.83	0.97
	Absorbed.....	.82	1.0
Analysis of product {	S, %.....	18.7	...
	N, %.....	8.6	8.7

Calcd. for $C_3H_8O_3NS$: S, 18.7; N, 8.2.

The writers take pleasure in expressing their thanks to Mr. John G. Womack, for his contribution to this work.

Summary

A study has been made of a number of derivatives of β -sulfopropionic acid, including a series of esters, the chloride, the anilide and the ammonium salt of the imide, which is the aliphatic analog of the corresponding salt of saccharin. This last substance was not sweet.

The free imide underwent complete hydrolysis when formed in aqueous solutions, and it was not produced by the pyrolysis of diammonium β -sulfopropionate at 111° and 3–4 mm., which yielded the acid ammonium salt almost quantitatively.

Seven new compounds have been characterized.

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