

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF JOHNS HOPKINS UNIVERSITY]

DERIVATIVES OF ANTHRAQUINONE. REACTIONS OF ANTHRAQUINONE SULFONIC ACIDS WITH MERCAPTANS¹

BY W. S. HOFFMAN AND E. EMMET REID

Received May 16, 1923

In a recent paper by Reid, Mackall and Miller² it has been shown that sulfonic acid groups in the α -position in anthraquinone are readily replaced by mercaptan residues to form anthraquinone thio-ethers, thio-ether sulfonic acids, and dithio-ethers, $C_{14}H_7O_2.SR$, 1,5- and 1,8- $RS.C_{14}H_6O_2.SO_3Na$ and 1,5- and 1,8- $C_{14}H_6O_2(SR)_2$.

The present investigation was undertaken to determine the best conditions for this reaction and to extend it to other mercaptans, particularly those of other types.

The speed of the reaction depends on the concentration of the sodium salt of the mercaptan and, hence, on account of the weakness of mercaptans as acids, is increased by excess of alkali. Alkali, however, tends to salt out the sodium anthraquinone sulfonate. Practically the maximum yield is reached with 4 equivalents of alkali and 4 hours' heating.

Previous work had shown that the reaction takes place with primary aliphatic mercaptans but not with aromatic. Benzyl mercaptan has been tried and has been found to work well, yielding well-characterized derivatives. *p*-Nitrobenzyl mercaptan reacts rapidly but the products are complex, extremely insoluble and difficult to handle, and so were discarded.

No difficulty was found in obtaining good yields of characteristic reaction products with *isopropyl* mercaptan, but the corresponding sulfones are obtained in small yield, if at all, since the $-SCH(CH_3)_2$ group is readily oxidized to $-SO_3H$ and the sulfonic acids are obtained quantitatively if the oxidation is vigorous. In the case of mixed dithio-ethers an *isopropyl* group is oxidized to the sulfonic acid while, with the other, oxidation stops at the sulfone: $RS.C_{14}H_6O_2.SCH(CH_3)_2 \longrightarrow RSO_2.C_{14}H_6O_2.SO_3H$. Small yields of sulfones may be obtained from the 1- and the 1,5-, but none from the 1,8-dithio-ethers containing an *isopropyl* group. Monothio-ethylene glycol has been found to react normally, its reaction rate being greater than those of the simple mercaptans on account of its solubility in water and low volatility. The resulting hydroxy-thio-ethers are slightly soluble in water and readily act with hydrosulfite.

Ethylene mercaptan was found to react rapidly but the products are complicated and could not be purified; the principal one from the monosulfonic acid seemed to be the disulfide, $C_{14}H_7O_2.SC_2H_4S.SC_2H_4S.C_{14}H_7O_2$.

¹ From a dissertation presented by W. S. Hoffman in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

² Reid, Mackall and Miller, *THIS JOURNAL*, **43**, 2104 (1921).

1,5-Anthraquinone-butyl-sulfone-sodium sulfonate, $C_4H_9SO_2C_{14}H_6O_2 \cdot SO_3Na$, was prepared by the oxidation of the corresponding thio-ether with fuming nitric acid. It is quite soluble in water; it separates from hot water with half a molecule of water of crystallization and from cold with 1 molecule. As previously shown, the thio-ether anthraquinone sodium sulfonate reacts with mercaptans, but on account of its extremely slight solubility even in boiling water, the reaction is very slow. Possibly on account of its far greater solubility, possibly partly on account of greater reactivity, the sulfone-sulfonate mentioned above reacts extremely rapidly with mercaptans in hot alkaline solution to give sulfone-thio-ethers, $1,5-C_4H_9SO_2 \cdot C_{14}H_6O_2 \cdot SR$, which appear as precipitates the instant that the mercaptans are added to the mixture. The yields are practically quantitative. In fact the reaction may advantageously be used for the identification of mercaptans. The melting points of the butyl sulfone-alkylthio-ethers so formed are definite but it is better to oxidize with fuming nitric acid to the mixed disulfones. These are particularly easy to purify and have good melting points. A number of these are given in previous article.³ Satisfactory results may be obtained with very small quantities of the mercaptans.

The great reactivity of the butyl-sulfone-anthraquinone sodium sulfonate toward mercaptans suggested that it might react with some compounds with which the sodium-anthraquinone sulfonates do not react. This has proved to be true with thiophenol which reacts at a satisfactory rate to give a good yield of butyl-sulfone-anthraquinone-thiophenol ether, $C_4H_9SO_2 \cdot C_{14}H_6O_2 \cdot SC_6H_5$, but the reaction does not go as fast and the yield is not as good as with the aliphatic mercaptans. *p*-Nitrothiophenol was tried in a similar manner. No product separated from the alkaline solution, which may be explained by the probable formation of some sort of sodium salt. After 4 hours' boiling the mixture was acidified and gave a brown solid which proved difficult to purify and was discarded. The reaction evidently takes place, but not smoothly.

It was thought that perhaps alcohols might react to give oxygen ethers. Butyl alcohol was added to the boiling alkaline solution of butyl-sulfone-anthraquinone sodium sulfonate and boiled for some time, but there was no indication of a reaction.

Experimental Part

Preparation of Butyl-anthraquinone Thio-ether. The effect of time, dilution and quantity of alkali upon the preparation of this substance as described in the preliminary article has been studied. In each experiment 3 g. of the sodium anthraquinone sulfonate was used and 1.25 equivalents of butyl mercaptan in boiling solution. The product was filtered on a small Büchner funnel, well washed with hot water, dried and weighed.

³ Ref. 2, p. 2113.

TABLE I
Volume, 150 cc. 4 eq. NaOH

Time, hours.....	1	2	4	6	8
Yield, %.....	59	75	78	84	85

TABLE II
4 hours. 4 eq. NaOH

Volume, cc.....	75	150	300	600
Yield, %.....	86.4	78.5	57.8	24.5

TABLE III
4 hours. Volume, 75 cc.

Eq. NaOH.....	0	1	2	4	8
Yield, %.....	0	67	80	86	85

The best conditions are 4 hours' boiling, 25 parts of water and 4 equivalents of sodium hydroxide.

Reactions with Benzyl and *p*-Nitrobenzyl Mercaptans

Preparation of Mercaptans.—Benzyl mercaptan was prepared by a slight modification of the general method given by Märcker.⁴ One and a half moles of crystallized sodium sulfide was melted at 90° on a water-bath and was saturated with hydrogen sulfide. To this was added an equal volume of ethyl alcohol, and the mixture was resaturated with hydrogen sulfide; finally a mole of benzyl chloride dissolved in alcohol was added. The mixture was allowed to stand in the cold, with frequent shaking for 4 days, kept cold if necessary with running water to prevent as much as possible the oxidation of the mercaptan to the disulfide and the formation of the monosulfide, both of which reactions take place readily at high temperatures. The mixture was then diluted with water, the mercaptan separated and distilled under reduced pressure.

We were unable to prepare *p*-nitrobenzyl mercaptan in this way, although Strakosch⁵ maintains that he did. Nor was the method proposed by Price and Twiss⁶ found successful. The method finally employed was that of Waters⁷. *p*-Nitrobenzyl thiocyanate (made by the action of potassium thiocyanate on an alcohol-water solution of *p*-nitrobenzyl bromide) was dissolved in cold alcohol and saturated with hydrogen chloride, and allowed to stand cold for 8 days. Upon the addition of water, *p*-nitrobenzyl thiocarbamine ester (*p*-NO₂C₆H₄CH₂SCONH₂) separated, and was removed, dissolved in alcohol, and heated with a little more than 1 equivalent of zinc acetate. The cooled mixture was poured into a large quantity of water, precipitating the zinc *p*-nitrobenzyl mercaptide, which was separated, and decomposed with concd. hydrochloric acid, liberating the free mercaptan that melted when pure at 52°.

Reaction of Mercaptans.—Benzyl mercaptan was caused to react with 1-anthraquinone sodium sulfonate, with 1,5- and 1,8-disodium sulfonates and with the thioether sodium sulfonates prepared by Reid, Mackall and Miller. The reactions were slower than with butyl mercaptan, so the time of heating was lengthened to 8 to 10 hours. The thio-ethers so obtained were converted to sulfones by solution in glacial acetic acid, addition of slight excess of concd. water solution of chromic anhydride and heating for half an hour. As this mixture cooled the sulfones separated as yellowish-white crystals which were quite pure.

⁴ Märcker, *Ann.*, **136**, 76 (1865).

⁵ Strakosch, *Ber.*, **5**, 692 (1872).

⁶ Price and Twiss, *J. Chem. Soc.*, **95**, 1726 (1909).

⁷ Waters, *Dissertation*, Munich, 1905.

Properties and analyses of the products are given in tabular form. The thio-ethers were recrystallized from solvent naphtha and the sulfones from acetic acid. The salts in Table V are orange-colored.

TABLE IV
BENZYL-ANTHRAQUINONE THIO-ETHERS

	Formula	M. p. ° C.	Sulfur		Color
			Calc. %	Found %	
1-Benzyl ⁸	C ₁₄ H ₇ O ₂ .SC ₇ H ₇	242	9.71	8.87	Golden-yellow
1,5-Dibenzyl.....	C ₁₄ H ₆ O ₂ (SC ₇ H ₇) ₂	176	14.17	14.50	Dull orange
1,8-Dibenzyl.....	C ₁₄ H ₆ O ₂ (SC ₇ H ₇) ₂	189	14.17	14.34	Orange-red

TABLE V
BENZYL-THIO-ETHER-ANTHRAQUINONE SODIUM SULFONATES

Formula	Water		Sodium Dry basis	
	Calc. %	Found %	Calc. %	Found %
1,5-C ₇ H ₇ S.C ₁₄ H ₆ O ₂ .SO ₂ Na.2H ₂ O.....	7.69	6.95	5.32	5.24
1,8-C ₇ H ₇ S.C ₁₄ H ₆ O ₂ .SO ₂ Na.3H ₂ O.....	11.11	11.80	5.32	5.72

TABLE VI
ALKYL-BENZYL-ANTHRAQUINONE-DITHIO-ETHERS. RS.C₁₄H₆O₂.SC₇H₇

Alkyl, R	M. p.		Sulfur Calc. %	Sulfur found			Color
	1,5- ° C.	1,8- ° C.		1,5- %	1,8- %	1,8- %	
Methyl.....	276	262	17.03	17.31	16.96	Gold	Crimson
Ethyl.....	208	164	16.43	16.86	16.81	Orange	Orange
Propyl.....	210	181	15.86	16.02	16.04	Orange	Orange
Butyl.....	235	185	15.32	15.18	15.03	Orange-yellow	Orange-red
<i>iso</i> -Propyl.....	239	229	15.86	16.18	16.12	Orange	Orange-red
<i>iso</i> -Amyl.....	211	189	14.83	15.00	14.99	Orange	Orange-red

TABLE VII
BENZYL-ANTHRAQUINONE SULFONES

Formula	M. p. ° C.	Sulfur %	
		Calc. %	Found %
1-Benzyl ⁹	233
1,8-Dibenzyl.....	202	12.42	12.30

TABLE VIII
ALKYL-BENZYL-ANTHRAQUINONE DISULFONES, RSO₂.C₁₄H₆O₂.SO₂C₇H₇

Alkyl, R	M. p.		Sulfur Calc. %	Sulfur found	
	1,5- ° C.	1,8- ° C.		1,5- %	1,8- %
Methyl.....	280	255	14.56	14.68	14.48
Ethyl.....	210	242.5	14.11	13.98	14.22
Propyl.....	215	227	13.69	13.70	13.80
Butyl.....	228	210	13.29	13.41	13.20
<i>iso</i> -Propyl.....	229	...	13.69	13.85	...
<i>iso</i> -Amyl.....	202	201	12.91	12.75	12.60

⁸ Prepared by Gattermann, who gave m. p. 240° [*Ann.*, **393**, 113 (1912)].

⁹ Prepared by Gattermann, who gives m. p. 231° (Ref. 8, p. 139).

Reactions with Iso-Propyl Mercaptan

Preparation of iso-Propyl Mercaptan.—The mercaptan was prepared in the same way as benzyl mercaptan, using *iso*-propyl bromide as described by Claus.¹⁰ The reaction mixture, in this case, after 4 days was distilled on the water-bath. The distillate was diluted with water, the mercaptan separated, dried over calcium chloride and re-distilled; yield, 60%.

Reactions with Anthraquinone Sodium Sulfonates.—The speed of reaction of this substance with anthraquinone sulfonic acids at 100° was naturally very low on account of the low boiling point, 57°. The mixtures were refluxed for 12 hours and the yields averaged above 40%. The properties of the derivatives formed are given in the tables below.

TABLE IX

ISO-PROPYL-ANTHRAQUINONE-THIO-ETHERS

	Formula	M. p. ° C.	Sulfur		Color
			Calc. %	Found %	
1- <i>iso</i> Propyl.....	C ₁₄ H ₇ O ₂ .SCH(CH ₃) ₂	134	11.36	11.37	Gold
1,5-Di- <i>isopropyl</i>	C ₁₄ H ₉ O ₂ [SCH(CH ₃) ₂] ₂	148	17.99	18.04	Orange
1,8-Di- <i>isopropyl</i>	C ₁₄ H ₉ O ₂ [SCH(CH ₃) ₂] ₂	181	17.99	18.33	Orange-red

TABLE X

ISO-PROPYL-THIO-ETHER-ANTHRAQUINONE SODIUM SULFONATES

Formula	Water		Sodium		Dry basis	
	Calc. %	Found %	Calc. %	Found %	Calc. %	Found %
1,5-(CH ₃) ₂ CHS.C ₁₄ H ₉ O ₂ .SO ₃ Na.2H ₂ O.....	8.57	7.80	5.98	5.70	5.98	5.78
1,8-(CH ₃) ₂ CHS.C ₁₄ H ₉ O ₂ .SO ₃ Na.3H ₂ O.....	12.33	11.64	5.98	5.78		

TABLE XI

ALKYL ISO-PROPYL-ANTHRAQUINONE-DITHIO-ETHERS, RS.C₁₄H₉O₂.SCH(CH₃)₂

Alkyl, R	M. p.		Sulfur calc. %	Sulfur found		1,5- %	1,8- %	Color	1,8-
	1,5- ° C.	1,8- ° C.		1,5- %	1,8- %				
Methyl.....	184	189	19.53	19.58	19.63	orange		crimson	
Ethyl.....	163	176	18.73	19.01	18.52	gold		crimson	
Propyl.....	133	135	17.99	18.24	18.13	gold		orange-red	
Butyl.....	114	131	17.31	17.40	17.71	orange-yellow		orange-red	
<i>iso</i> -Amyl.....	97	109	16.68	16.24	16.78	brownish		orange-red	

Oxidation of Iso-propyl-anthraquinone-thio-ether and dithio-ethers

On oxidation of α -*iso*-propyl-anthraquinone-thio-ether with fuming nitric acid, 81% was converted into α -anthraquinone sulfonic acid which was identified by conversion into butyl-anthraquinone-thio-ether; m. p. 114°. A small amount of the sulfone, (CH₃)₂CHSO₂.C₁₄H₇O₂, was obtained, m. p. 182°

Calc. for C₁₇H₂₁O₄S: S, 10.20. Found: 10.30.

Similarly, the 1,5 mixed dialkyl dithio-ethers containing *isopropyl* gave small yields of the disulfones, 80 to 85% being oxidized to the alkyl sulfone-sulfonic acids. The melting points and analyses of these disulfones are given in Table XII.

¹⁰ Claus, *Ber.*, 5, 656 (1872).

From the corresponding 1,8-dithio-ethers no disulfones could be obtained. The 1,8-anthraquinone disulfonic acid resulting from the oxidation of the di-*isopropyl*-dithio-ether was titrated and required over 96% of the calculated amount of alkali.

The 1,5- and 1,8-alkyl sulfone-sulfonic acids obtained above were boiled with butyl mercaptan under the usual conditions and converted into the corresponding alkyl sulfone-butyl-thio-ethers, the melting points of which are given in Table XIII. All are yellow solids very slightly soluble in water. For identification they were oxidized to the dialkyl disulfones described in the previous article.

TABLE XII

1,5-ALKYL-ISOPROPYL-ANTHRAQUINONE DISULFONES, $\text{RSO}_2\cdot\text{C}_{14}\text{H}_6\text{O}_2\cdot\text{SO}_2\text{CH}(\text{CH}_3)_2$						
<i>iso</i> Propyl alkyl	Methyl	Ethyl	Propyl	Butyl	<i>iso</i> Propyl	<i>iso</i> Amyl
M. p., ° C.	235	213	203	186	222	172
Sulfur, calc., found	16.34, 16.60;	15.78, 16.00;	15.25, 15.31;	14.76, 14.92;	14.30, 14.20;	15.25, 15.38

TABLE XIII

ALKYL SULFONE-BUTYL-THIO-ETHERS, $\text{RSO}_2\cdot\text{C}_{14}\text{H}_6\text{O}_2\cdot\text{SC}_4\text{H}_9$					
Alkyl	Methyl	Ethyl	Propyl	Butyl	<i>iso</i> Amyl
M. p., 1,5-:1,8-, ° C.	256:162	210:140	204:132	162:126	189:121

Reactions with Monothio-ethylene Glycol

This mercaptan was prepared according to the methods of Rosen and Reid¹¹ and of Bennett.¹² When freshly prepared it reacted with the anthraquinone sulfonic acids under the same conditions as did butyl mercaptan with about the same yields, but poor results were obtained when the mercaptan was not fresh. The monothio-ether had been previously prepared by Gattermann by another method. He gives the same melting point. Owing to the presence of the hydroxyl group, these thio-ethers show a slight solubility in water. The data for the compounds prepared are found in Table XIV. The acetates were made by treating with acetyl chloride and were recrystallized from acetic acid, the hydroxy compounds from butyl alcohol.

TABLE XIV
DERIVATIVES OF MONOTHIO-ETHYLENE GLYCOL

Substituents	M. p. ° C.	Calc. %	Found %	Sulfur	Color
1-SCH ₂ CH ₂ OH.....	178		orange
1-SCH ₂ CH ₂ OCOCH ₃	146		yellow
1,5-(-SCH ₂ CH ₂ OH) ₂	224	17.79	17.37		orange
1,5-(-SCH ₂ CH ₂ OCOCH ₃) ₂	199	14.43	14.60		yellow
1,8-(-SCH ₂ CH ₂ OH) ₂	206	17.79	17.30		red
1,8-(-SCH ₂ CH ₂ OCOCH ₃) ₂	159	14.43	14.54		yellow

¹¹ Rosen and Reid, *THIS JOURNAL*, **44**, 634 (1922).

¹² Bennett, *J. Chem. Soc.*, **120**, 422 (1921).

Reactions with Ethylene Mercaptan

Preparation of Ethylene Mercaptan.—Ethylene mercaptan was made according to the method of Fasbender¹³ with the following modifications. The mixture of the alcohol-water solution of sodium hydrosulfide and of ethylene bromide was allowed to stand for 4 days in cold water, with frequent shaking. The mixture was diluted with water, the mercaptan layer filtered off, dried with calcium chloride and distilled under reduced pressure; yield, about 30%. The mercaptan is exceedingly unstable and gives on heating a large quantity of a white crystalline compound. It is the formation of this compound, containing a high percentage of sulfur that made a study of the reactions of ethylene mercaptan so difficult.

Reaction of Ethylene Mercaptan with Anthraquinone Sulfonic Acids.—Ethylene mercaptan was found to react quite readily with the mono- and disulfonates, giving yields of about 80% of yellow powders. In every case, however, these powders were impure, giving various analyses for sulfur and no definite melting points. One attempt at purification of the monosulfonate reaction product gave a substance that contained 21.75% of sulfur. It did not melt below 250°, showing the absence of appreciable sulfur-containing impurities which were found in most cases to lower the melting points of the crude products to below 100°. The analysis points to the possible compound, $C_{14}H_7O_2 \cdot SCH_2CH_2S \cdot SCH_2CH_2S \cdot C_{14}H_7O_2$ (sulfur: calc., 21.42%), an oxidation product of the derivative $C_{14}H_7O_2SCH_2CH_2SH$ first formed.

1,5-Butyl-anthraquinone-sulfone Sodium Sulfonate,

$C_{14}H_9SO_2 \cdot C_{14}H_6O_2 \cdot SO_3Na$, and its Reactions

The thio-ether sodium sulfonate, or "gold salt," is dissolved in about 2 parts by weight of fuming nitric acid and the solution evaporated to dryness on the water-bath. The oxidation to the sulfone-sulfonate is practically quantitative. This substance was dissolved in a minimum amount of hot water and the solution evaporated until crystals formed. These were separated and the solution was cooled. Nothing further separated until the temperature was below 30°. The crystals from hot water contained 2.89% of water and those from cold, 3.59%; calc.: 0.5 H₂O, 2.05%; 1 H₂O, 4.02%.

The sulfone sodium sulfonate is far more soluble and reacts with mercaptans far more rapidly than the thio-ether sodium sulfonate.

To a boiling solution of 2 g. of this salt in 50 cc. of water, with 4 equivalents of sodium hydroxide, butyl mercaptan was added in slight excess. The butyl-thio-ether-anthraquinone-butyl-sulfone separated immediately. The boiling was continued for a few minutes and the crystals were separated and washed with hot water. The yield was practically quantitative.

Analysis. Calc. for $C_{14}H_9S \cdot C_{14}H_6O_2 \cdot SO_2 \cdot C_4H_9$: S, 15.40. Found: 15.37.

Fuming nitric acid oxidized it to 1,5-dibutyl-anthraquinone-disulfone, m. p., 184.5°, as described by Reid, Mackall and Miller. Corresponding products were made from other mercaptans. Because of the volatility of methyl mercaptan the reactants were sealed in a tube which was then suspended in boiling water. The melting points of thio-ether-sulfones and the disulfones into which they were converted by oxidation are given in Table XV.

¹³ Fasbender, *Ber.*, 20, 460 (1887).

TABLE XV

ALKYL THIO-ETHER-ANTHRAQUINONE-BUTYL-SULFONES AND DISULFONES					
Alkyl, R	Methyl	Ethyl	Propyl	Butyl	isoAmyl
$\text{R.S.C}_{14}\text{H}_8\text{O}_2\text{SO}_2\text{C}_4\text{H}_9$, m. p., ° C.	228	214	201	162	152
$\text{RSO}_2\text{C}_{14}\text{H}_8\text{O}_2\text{SO}_2\text{C}_4\text{H}_9$, m. p., ° C.	264	194	220	184.5	203.5

This reaction, which takes place so quickly and with such high yields, offers an excellent means of identifying mercaptans. For some unknown reason, the melting points of the alkyl thio-ether-butyl-sulfones are not as sharp as is desirable but the disulfones into which they are readily oxidized are excellent derivatives for identification as they are readily purified and melt sharply.

Thiophenol reacts with the butyl-sulfone sodium sulfonate under the same conditions as the mercaptans, though the reaction is slower; yield, 80%. The compound was recrystallized from acetic acid and did not melt even at 350°.

Analysis. Calc. for $\text{C}_6\text{H}_5\text{S.C}_{14}\text{H}_8\text{O}_2\text{SO}_2\text{C}_4\text{H}_9$: S, 14.69. Found: 15.11.

The same reaction takes place with *p*-nitro-thiophenol though the product remains in solution in the excess of alkali from which it was precipitated by acidifying. The product was extremely insoluble and difficult to purify. It melted above 300° and contained 14.03% of sulfur; calc., 13.32%.

Several attempts were made to prepare the oxygen ether, $\text{C}_4\text{H}_9\text{O.C}_{14}\text{H}_8\text{O}_2\text{SO}_2\text{C}_4\text{H}_9$, by using butyl alcohol instead of the mercaptan but no such compound could be obtained. Long boiling in alkaline solution does not give any appreciable amount of the hydroxy derivative.

Summary

The replacement of sulfonic acid groups in the anthraquinone-sulfonic acids has been further studied using benzyl, *p*-nitrobenzyl, and *isopropyl* mercaptans and mono- and dithio-ethylene glycols. All of these react, but the second and last do not give products that can be purified.

The *isopropyl*-thio-ethers can sometimes be oxidized to sulfones but usually go to the sulfonic acids.

When 1,5-butyl-thio-ethers-anthraquinone sodium sulfonate is oxidized, the corresponding butyl-sulfone sulfonate is obtained in quantitative yield. This reacts extremely rapidly with mercaptans to form 1,5-butyl-sulfone-anthraquinone alkyl thio-ethers. This reaction offers a ready method for the identification of mercaptans.

BALTIMORE, MARYLAND