

homologs agree well with the suggestion that these compounds react with molecular oxygen to form quinones and hydrogen peroxide.

4. Hydrogen peroxide oxidizes the sulfite to sulfate.

5. If the quinone formed has at least one nuclear hydrogen, it reacts with the sulfite with formation of the corresponding hydroquinone monosulfonate.

6. The hydroquinone monosulfonate is autoxidized and the oxidation products undergo the reactions mentioned under (4), and, if the conditions are fulfilled, (5); thus, hydroquinone monosulfonate and toluhydroquinone monosulfonate form the disulfonates.

7. The oxidation of hydroquinone in sulfite solution does not follow a simple first-order law. The dependence of the reaction rate on the con-

centrations of oxidand and oxygen, and on the pH are in good agreement with a mathematical expression found on the assumption that the inhibitory action of sulfite is due to the removal of quinone which acts as a catalyst for the autoxidation.

8. The linear dependence on the sulfite concentration which has been observed throughout the whole range of the experiments does not follow from this expression.

9. The inhibitory action of thiol compounds (cysteine, thioglycolic acid, thiocresol, etc.) also agrees with the assumption that their action is caused by the removal of the catalyzing quinone.

10. The autoxidation of various reaction products of quinones with thiol compounds has been measured.

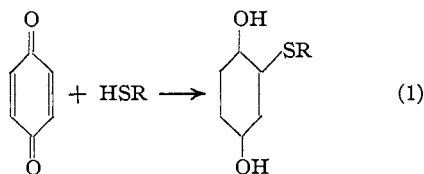
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[COMMUNICATION NO. 710 FROM THE KODAK RESEARCH LABORATORIES]

The Reaction of Thiol Compounds with Quinones

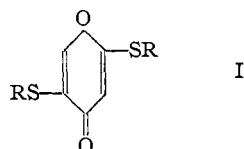
BY J. M. SNELL AND A. WEISSBERGER

In connection with work on the inhibitory action of thiol compounds in the autoxidation of hydroquinones,^{1,2} some experiments were made on the reaction of thiol compounds with benzoquinone and substituted benzoquinones. Two types of reaction may be expected: (A), oxidation of the thiol to a disulfide with reduction of the quinone to the hydroquinone; (B), addition of the thiol to the quinone according to (1)

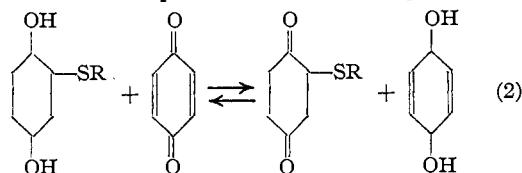


They are analogous to the reactions of quinones with sulfite.³ Both types have been recorded in the literature. Bongartz⁴ observed that quinone and thioglycolic acid in the absence of a solvent form hydroquinone. Tarboureich⁵ caused quinone and ethyl mercaptan to react under widely varying conditions and, in all cases, even at 140° in a bomb, isolated only hydroquinone or quin-

hydrone. Addition products were isolated by Troeger and Eggert⁶ and by Posner,⁷ who added various thiols to quinone in ligroin solution and treated the resulting molecular compounds with alcohol. Working with a four-fold excess of quinone, only disubstituted quinones of the type I were obtained.⁷ Sharvin and Lukin⁸ added thiosalicylic acid to quinone in xylene and also



obtained a disubstituted quinone, quinonedithiosalicylic acid. Our own experiments which are described below suggest that these reactions proceed according to (1), that the substituted hydroquinone is in equilibrium with the quinone (2),



(1) James, Snell and Weissberger, *THIS JOURNAL*, **60**, 2084 (1938).

(2) James and Weissberger, *ibid.*, **61**, 442 (1939).

(3) Dodgson, *J. Chem. Soc.*, **105**, 2435 (1914).

(4) Bongartz, *Ber.*, **21**, 483 (1888).

(5) Tarboureich, *Bull. soc. chim.*, [3] **25**, 313 (1901).

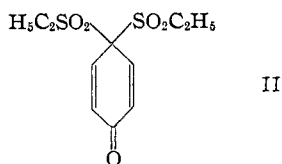
(6) Troeger and Eggert, *J. prakt. Chem.*, [2] **53**, 482 (1896).

(7) Posner, *Ann.*, **336**, 85-167 (1904).

(8) Sharvin and Lukin, *J. Russ. Phys. Chem. Soc.*, **59**, 217-20 (1927); *C. A.*, **22**, 1583 (1928).

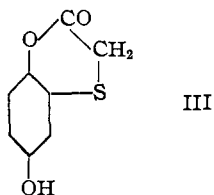
and that repetition of reactions of types (1) and (2) yields the disubstituted quinones.

An entirely different type of compound was described by Récesei,⁹ who added ethyl mercaptan to quinone in glacial acetic acid while passing in dry hydrogen chloride, and oxidized the resulting sirup with permanganate to, as he believed, 1,1-bis-ethane sulfonyl cyclohexadiene-2,5-one-4 (II).



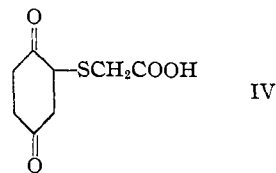
Following his procedure, we obtained a compound with the properties described by Récesei, which, however, according to its elementary analysis, cannot have the constitution (II). The same compound is obtained in better yield with ferric chloride as oxidizing agent instead of permanganate, and ferric chloride is hardly to be expected to produce a sulfone. No further investigation of this compound was made because we were interested mainly in the reactions taking place in aqueous or aqueous alcoholic solutions under mild conditions.

On addition of aqueous thioglycolic acid to an alcoholic solution of one mole of quinone, a homogeneous, colorless solution was obtained. Removal of solvents and thioglycolic acid *in vacuo* left a strongly acidic sirup. On standing for a long time in a desiccator or on heating to about 150°, this gave off water and formed a white crystalline, phenolic but no longer acidic compound, hydroquinone α -thioacetic acid lactone (III).



The formation of this compound in a good yield indicates that the sirup consisted mainly of the hydroquinone thioacetic acid.

When the thioglycolic acid is added to two moles of quinone, a deep red solution results. On evaporation of the solvent, a red crystalline acidic substance, quinone α -thioacetic acid (IV) was obtained. The second molecule of quinone obviously oxidized the hydroquinone thioacetic



acid, according to (2). Reduction of (IV) with zinc dust and acetic acid gave (III).

Quinonethioacetanilide was prepared in a similar way.

Equimolar amounts of thiophenol and quinone in alcoholic solution gave a light brown sirup from which only a very small amount of a red compound Posner's *bis*-thiophenylquinone, could be crystallized. With two equivalents of quinone, however, a good yield of monothiophenyl-*p*-benzoquinone was obtained. Reduction yielded a sirupy material which again could not be crystallized, and was identified as the monothiophenylhydroquinone after conversion into a crystalline diacetate.

With β -thiopropionic acid as well as ethyl mercaptan and octadecyl mercaptan, the addition reaction apparently is overtaken by the oxidation of the substituted hydroquinone by the benzoquinone. Thus, even with an excess of β -thiopropionic acid, quinone- β -thiopropionic acid and quinone-*bis*- β -thiopropionic acid were obtained in approximately equal amounts. With ethyl mercaptan, the only products isolated were small amounts (6%) of hydroquinone and *bis*-thioethyl-*p*-benzoquinone. The latter compound separated readily from the reaction mixture because of its slight solubility in alcohol. A somewhat better yield (20%) was obtained with quinone and excess ethyl mercaptan at 100°.

Pseudocuminoquinone, which has only one free position on the nucleus gives, with thioglycolic acid as well as with octadecyl mercaptan, the primary addition products in good yield. The trimethylhydroquinone thioglycolic acid was oxidized by ferric chloride to the corresponding quinone. With octadecyl mercaptan, trimethylthio-*n*-octadecyl-*p*-benzoquinone was obtained, and reduced to the corresponding hydroquinone by zinc and acetic acid. These results cast doubt on Posner's statement⁷ (p. 166) that xyloquinone and thiophenol in various solvents do not react. Therefore, *p*-xyloquinone and thiophenol were mixed in alcoholic solution and 2-thiophenyl-3,6-dimethyl-*p*-benzoquinone was obtained in fair yield.

Duroquinone and thioglycolic acid in alcoholic

(9) Récesei, *Ber.*, 60, 1836 (1927).

solution did not react. When, however, the acid was neutralized with a slight excess of sodium carbonate, an immediate reaction of type A took place with separation of durohydroquinone.

Experimental Part

Hydroquinone α -Thioacetic Acid Lactone, III.—Thioglycolic acid, (9.2 g., 0.1 mole) in water (200 ml.) was added gradually to a solution of 10.8 g. (0.1 mole) of quinone in 95% ethanol (200 ml.). The solution became colorless in a few minutes. The solvents were removed *in vacuo* and the residue was heated in an oil-bath at 150° for three hours. Water was gradually evolved. On cooling, the residue crystallized to a white mass. Recrystallization from 50% ethanol gave 6.6 g. (36%) of crude product, m. p. 162–170°, which was purified by sublimation *in vacuo* (1 mm. at 180°) followed by recrystallization from water or dilute alcohol; m. p. 169–171°.

Anal. Calcd. for $C_8H_8O_3S$: C, 52.7; H, 3.3; S, 17.61. Found: C, 52.6; H, 3.41; S, 17.31.

Quinone- α -thioacetic Acid, IV.—Thioglycolic acid (4.6 g.) was added at once to a solution of quinone (10.8 g.) in 95% ethanol (200 ml.). The solution became warm and dark red. After thirty minutes (longer standing results in losses), the alcohol was removed *in vacuo* and the residue was recrystallized from 50% ethanol, then from water, and washed with water until free from black material. A final recrystallization from water gave 3.2 g. (32.4%) of brick-red product, m. p. 157–158° (d.).

Anal. Calcd. for $C_8H_7O_3S$: C, 48.5; H, 3.0. Found: C, 48.5; H, 3.0.

The quinone was converted into the hydroquinone lactone by adding zinc dust in small portions to a hot solution of the quinone in glacial acetic acid until the solution became colorless. The solution was filtered hot, and the acetic acid distilled from the filtrate *in vacuo*. The residue was recrystallized from water; m. p. and mixed m. p. with product obtained as described above 169–170°.

Quinone- α -thioacetanilide, V.—Thioglycolic anilide¹⁰ (0.33 g., 0.002 mole) dissolved in ethanol (15 ml.) was treated with 0.43 g. (0.004 mole) of quinone in ethanol (15 ml.). The bright red precipitate was collected and recrystallized from bromobenzene. The yield of pure product, m. p. 175–176°, ¹¹ was 0.2 g. (36.5%).

Thiophenyl-*p*-benzoquinone was prepared from quinone and thiophenol, using the procedure described for quinone-thioacetic acid except that both reactants were dissolved in ethanol; yield 92.5%. After two recrystallizations from ethanol and one from ligroin, m. p. 110–112°.

Anal. Calcd. for $C_{12}H_8O_2S$: C, 66.4; H, 4.14. Found: C, 66.5; H, 3.81.

Thiophenylhydroquinone Diacetate.—Thiophenyl-*p*-benzoquinone (0.5 g.) in glacial acetic acid was shaken with zinc dust until it became colorless. The acetic acid was evaporated *in vacuo*, leaving a colorless sirup which did not crystallize. This was acetylated with acetic anhydride

and a drop of sulfuric acid at 100° for thirty minutes. The diacetate was recrystallized from 95% ethanol (Norite), then from hexane; m. p. 84–85°.

Anal. Calcd. for $C_{18}H_{14}O_4S$: C, 63.6; H, 4.6. Found: C, 63.4; H, 4.6.

bis-Thioethyl-*p*-benzoquinone.—Two grams of powdered *p*-benzoquinone and 15 ml. of ethyl mercaptan were heated in a sealed tube in a steam-bath for thirty minutes. After standing overnight, the excess mercaptan was evaporated and the residue twice recrystallized from alcohol; m. p. 158–159°; yield, 0.3 g. (21.3%).

Quinone-bis- β -thiopropionic Acid.— β -Thiopropionic acid¹² (2 g.) in ethanol (10 ml.) was added to quinone (4 g.) in ethanol (75 ml.). The solution was cooled in ice for one hour, and the red crystalline product was filtered off and washed with alcohol; yield, 0.9 g. (30.2%); m. p. about 240° (d.). The substance may be recrystallized from boiling nitrobenzene.

Anal. Calcd. for $C_{12}H_{12}O_6S_2$: C, 45.6; H, 3.8. Found: C, 45.7; H, 3.8.

Quinone β -Thiopropionic Acid.—The filtrate from the quinone-bis- β -thiopropionic acid was freed from solvent *in vacuo*, and the residue was recrystallized twice from 50% ethanol; yield, 1.3 g. (33%); m. p. 160–163°. After two extractions with boiling toluene and filtering off the less soluble impurities, the melting point was 165–166°.

Anal. Calcd. for $C_9H_8O_4S$: C, 51.0; H, 3.8. Found: C, 51.1; H, 3.8.

Hydroquinone- β -thiopropionic Acid.—Quinone- β -thiopropionic acid (0.4 g.) was reduced with zinc dust and glacial acetic acid. The acetic acid was removed *in vacuo*, and the hydroquinone was extracted from the residue with absolute ether. The residue from the ether slowly crystallized. After recrystallization from chloroform containing a trace of methanol, the product formed a white powder, m. p. 121–123°; yield, 0.2 g. (50%). It was extremely soluble in water, alcohol, glacial acetic acid, ether, ethyl acetate; insoluble in benzene, toluene, chloroform.

Trimethylhydroquinone- α -thioacetic Acid.—Pseudocumquinone (1.5 g., 0.01 mole) in ethanol (15 ml.) was added to thioglycolic acid (0.9 g., 0.01 mole) in water (10 ml.). The solution became warm but was not decolorized. After standing overnight, the alcohol was evaporated off, the residue was covered with benzene and dissolved in dilute (2 *N*) sodium carbonate solution. A little insoluble matter was filtered off and the filtrate was placed in a separatory funnel. The aqueous layer was run into a slight excess of dilute hydrochloric acid, and placed in the refrigerator overnight. The yield of white crystals was 1.5 g. (62.5%); m. p. 136° (d.). After recrystallization from 10% methanol, then from toluene, the melting point was 142° (d.). The melt frothed, resolidified, and melted again at about 190°.

Anal. Calcd. for $C_{11}H_{14}O_4S$: C, 54.5; H, 5.8; S, 13.2. Found: C, 54.6; H, 5.8; S, 12.7.

Trimethylquinone- α -thioacetic Acid.—Trimethylhydroquinone- α -thioacetic acid (0.1 g.) was suspended in a solution of ferric chloride crystals (1.5 g.) in 0.5 *N* hydrochloric acid (2 ml.). After standing for three hours, 2 ml. of ethanol was added and the mixture was heated to boiling

(10) B. Holmberg, *J. prakt. Chem.*, **84**, 650 (1911).

(11) M. P. Schubert, *J. Biol. Chem.*, **114**, 347 (1936), states that this compound is too insoluble to be recrystallized and melts at 165–166°.

(12) Biilmann, *Ann.*, **348**, 125 (1906).

for a few seconds until the solid had dissolved. On cooling, the quinone separated as an oil which soon crystallized. After recrystallization from chloroform-petroleum ether, then water, the orange product melted at 126–127°, softening at 123°.

Anal. Calcd. for $C_{11}H_{12}O_4S$: C, 55.0; H, 5.0. Found: C, 55.3; H, 5.0.

***n* - Octadecyl Mercaptan.**—*n*-Octadecyl isothioureahydrobromide was prepared according to the method of Sprague and Johnson.¹³ Free base, recrystallized from alcohol, m. p. 83–85°. The base was hydrolyzed according to the method of Backer, Terpstra, and Dijkstra¹⁴ to give the mercaptan, which was a colorless, viscous oil, b. p. (1 mm.) 165–170°.

Trimethyl - *n* - octadecyl - *p* - benzoquinone.—Octadecyl mercaptan (1.43 g., 0.005 mole) and ψ -cunoquinone (0.75 g., 0.005 mole) were mixed together with about 3 ml. of 95% ethanol and sufficient ether (about 3 ml.) to make a homogeneous solution. The solution gradually turned dark red, and deposited a soft, bright red solid. After standing for three days, the mixture was diluted with 60 ml. of absolute ethanol and 15 cc. of benzene. On cooling in ice, the quinone crystallized out. It was finally recrystallized from petroleum ether. It formed orange-red wax-like crystals melting at 71–73°. The yield was about 0.5 g.

Anal. Calcd. for $C_{27}H_{46}O_2S$: C, 74.7; H, 10.6. Found: C, 75.2; H, 10.7.

Trimethyl - *n* - octadecyl Hydroquinone.—Trimethyl-*n*-octadecyl quinone was dissolved in warm glacial acetic acid and shaken with a little zinc dust until colorless. The hydroquinone was precipitated from the filtrate with water, recrystallized from glacial acetic acid, and finally from petroleum ether. It was a white powder, m. p. 76–77°.

Anal. Calcd. for $C_{27}H_{48}O_2S$: C, 74.4; H, 11.0. Found: C, 74.2; H, 11.1.

Durohydroquinone.—Duroquinone (2 g., 0.0122 mole) and thioglycolic acid (2.5 g., 0.027 mole) were dissolved in warm 80% ethanol (30 ml.). No reaction occurred. The warm solution was made slightly alkaline with 2 *N* sodium carbonate and shaken. A dark gray precipitate formed,

(13) J. M. Sprague and T. B. Johnson, *THIS JOURNAL*, **58**, 1348 (1936); **59**, 1837 (1937).

(14) H. J. Backer, P. Terpstra and N. D. Dijkstra, *Rec. trav. chim.*, **51**, 1167 (1932).

which became peach colored on continued shaking. Water (50 ml.) was added, with a slight excess of hydrochloric acid. The precipitate was filtered off and recrystallized from glacial acetic acid; m. p. and mixed m. p. with authentic durohydroquinone, 234–235°; yield, 1.5 g. (75%).

2 - Thiophenyl - 3,5 - dimethyl - *p* - benzoquinone.—2-Thiophenyl-3,5-dimethyl-*p*-benzoquinone was prepared from thiophenol and *p*-xyloquinone, using the procedure described for thiophenyl-*p*-benzoquinone. The product was recrystallized from methanol; yield, 29%; m. p. 106–107°.

Anal. Calcd. for $C_{14}H_{12}O_2S$: C, 68.8; H, 4.9. Found: C, 68.9; H, 5.1.

Anal. of Récei Compound. Calcd. for $C_{10}H_{14}S_2O_5$ (II): C, 43.2; H, 5.0; S, 23.0. Found: C, 50.2; H, 5.6; S, 32.3.

Acknowledgment.—We are indebted to Dr. L. T. Hallett, of the Kodak Research Laboratories, for carrying out the microanalyses.

Summary

Thiols have been added to quinone and methyl substituted quinones in alcoholic or aqueous alcoholic solution. The products obtained were hydroquinone- α -thioacetic acid lactone, quinone- α -thioacetic acid, thiophenylhydroquinone, thiophenyl quinone, quinone- β -thiopropionic acid, quinone-*bis*- β -thiopropionic acid, trimethylhydroquinone α -thioacetic acid, trimethylthio-*n*-octadecyl quinone, dimethylthiophenylquinone, *bis*-thioethylquinone.

The reactions proceed with formation of a hydroquinone thioether, which may be oxidized to the quinonoid stage by part of the original quinone. Direct reduction of the quinone, the thiol being oxidized to the corresponding disulfide, has been observed with duroquinone and thioglycolic acid in the presence of alkali.

The compound described by Récei has been analyzed and its composition found to be different from that required by his formula.

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