STUDIES ON QUINONES

VI. Reaction of Anthra[1,2-c]-1,2,5-thiadiazole-6,11-dione with Nucleophilic Agents*

M. V. Gorelik and S. B. Lantsman

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In the reaction of anthra[1,2-c]-1,2,-5-thiadiazole-6,11-dione (I) with mercaptans, arylsulfinic acids, and bisulfite, the nucleophilic agent is directed into position 4 of the nucleus with the formation of substituted hydroquinones, the oxidation of which leads, respectively, to 4-aryl(alkyl)thio, 4-arylsulfonyl, and 4-sulfo derivatives of anthra [1,2-c]-1,2,5-thiadiazole-6,11-dione (II, VI, IX). When entry into position 4 is impossible, addition to the carbonyl oxygen atom takes place. On being heated with bisulfite, the quinonesulfonic acid IX is converted into the monsulfuric acid ester of the hydroquinonesulfonic acid X, and on reaction with benzenesulfinic acid 4-phenylsulfonylanthraquinonethiadiazole (VIa) is converted into the benzenesulfonic acid monoester XI.

The anthra[1,2-c]-1,2,5-thiadiazole-6,11-diones that we have described previously react readily not only with amines [1] but also with reagents containing a sulfur atom in the nucleophilic center: mercaptans, sulfinic acids, bisulfite.

Brief heating of the anthraquinonethiadiazole I with mercaptans in dimethylformamide and subsequent treatment with ferric chloride leads to the formation of 4-aryl(alkyl)thioanthra[1,2-c]-1,2,5-thiadiazole-6,11-diones (II) in high yield (table). A proof of the entry of the mercapto group into position 4 is the reaction

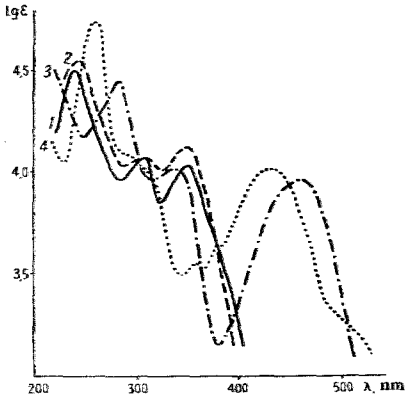


Fig. 1. Absorption spectra: 1) 4-phenylthioanthra[1,2-c]-1,2,5-thiadiazole-6,11-dione (IIa); 2) 4-phenylsulfonylanthra[1,2-c]-1,2,5-thiadiazole-6,11-dione (VIa); 3) anthra[1,2-c]-1,2,5-thiadiazole-6,11-dione-4-sulfonic acid (IX); 4) sulfuric acid monoester of 6,11-dihydroxyanthra[1,2-c]-1,2,5-thiadiazole-4-sulfonic acid (X).

of the halogen derivatives of anthraquinonethiadiazole III and IV with thiophenol. As in the reaction with amines [1], in the case of 4-chloroanthraquinonethiadiazole (III) the halogen atom is replaced and the same

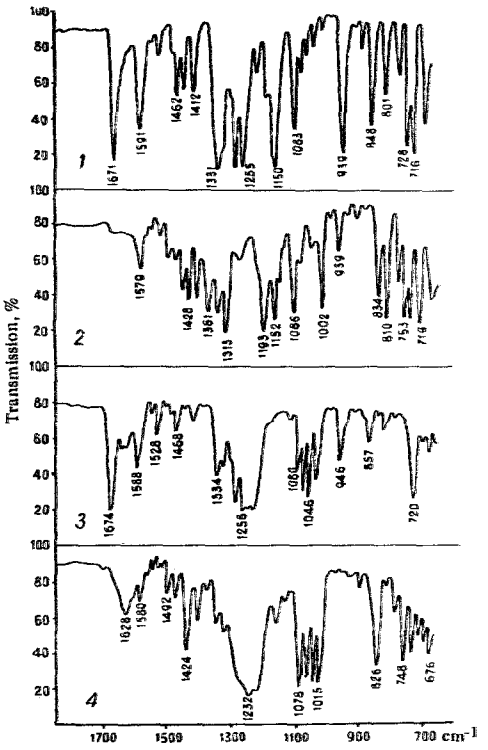


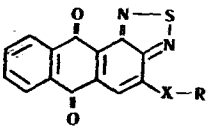
Fig. 2. IR spectra: 1) 4-phenylsulfonylanthra[1,2-c]-1,2,5-thiadiazole-6,11-dione (IIa); 2) benzenesulfonic acid monoester of 6,11-dihydroxyanthra[1,2-c]-1,2,5-thiadiazole (XI); 3) anthra[1,2-c]-1,2,5-thiadiazole-6,11-dione-4-sulfonic acid (IX); 4) sulfuric acid monoester of 6,11-dihydroxyanthra[1,2-c]-1,2,5-thiadiazole-4-sulfonic acid (X).

substance is formed as from quinone I, while in the case of the 5-chloro derivative (IV) the replacement of hydrogen takes place with conversion into the chlorine-containing sulfide V.

Analogously, by the reaction of arylsulfinic acids and subsequent oxidation, the anthraquinonethiadiazole I is smoothly converted into the 4-arysulfonyl-substituted derivates VI (table). The corresponding anthrahydroquinones VII are formed as intermediates, and these can easily be isolated by carrying out the reaction in acetic acid or can be obtained by reducing the quinones VI with stannous chloride. The position of the arylsulfonyl grouping on the fourth carbon atom follows from the synthesis of the sulfones VI by the treatment of the sulfides II with peracetic acid.

*For part V, see [1].

Sulfides and Sulfones of Anthra[1,2-c]-1,2,5-thiadiazole-6,11-dione



Compound	X	R	Mp, °C	λ_{max}, nm (lg ε)	Empirical formula	Found, %		Calculated, %		Yield, %
						N	S	N	S	
IIa	S	C_6H_5	270—271	460 (3.95)	$C_{20}H_{10}N_2O_2S_2$	7.49 7.20	17.16[a] 16.98	7.48	17.13	74
IIb	S	4-$CH_3C_6H_4$	301—302	465 (3.70)	$C_{21}H_{12}N_2O_2S_2$	6.97 7.05	—	7.21	—	71
IIc	S	2,4,5-$Cl_3C_6H_2$	268—269	440*	$C_{20}H_7Cl_3N_2O_2S_2$	5.98 6.02	13.53[b] 13.68	5.87	13.43	63
IId	S	CH_2COOH	259—260 (decomp.)	465 (3.78)	$C_{16}H_8N_2O_4S_2$	8.05 8.00	—	7.85	—	75
IIe	S	β-$C_{10}H_7$	274—275	465 (4.00)	$C_{24}H_{12}N_2O_2S_2$	6.84 6.57	14.75 14.88	6.60	15.11	65
VIIa	SO_2	C_6H_5	311—312	350 (4.12)	$C_{20}H_{10}N_2O_4S_2$	6.80 6.54	15.66 15.53	6.90	15.79	82 84**
VIIb	SO_2	4-$CH_3C_6H_4$	298—299 (decomp.)	350 (4.15)	$C_{21}H_{12}N_2O_4S_2$	6.92 6.82	15.16 14.99	6.66	15.26	73
VIIc	SO_2	4-BrC_6H_4	293—294	353 (4.17)	$C_{20}H_9BrN_2O_4S_2$	6.05 5.97	13.38[c] 13.31	5.78	13.20	70
VIId	SO_2	3-$NO_2C_6H_4$	301—302 (decomp.)	350 (4.15)	$C_{20}H_9N_3O_6S_2$	9.07 9.11	13.94 14.03	9.31	14.20	61
VIIe	SO_2	CH_2COOH	224—225 (decomp.)	350 (4.11)	$C_{16}H_8N_2O_6S_2$	7.24 7.18	16.81 16.73	7.21	16.52	71**

*Saturated solution.

**By oxidation of the sulfide.

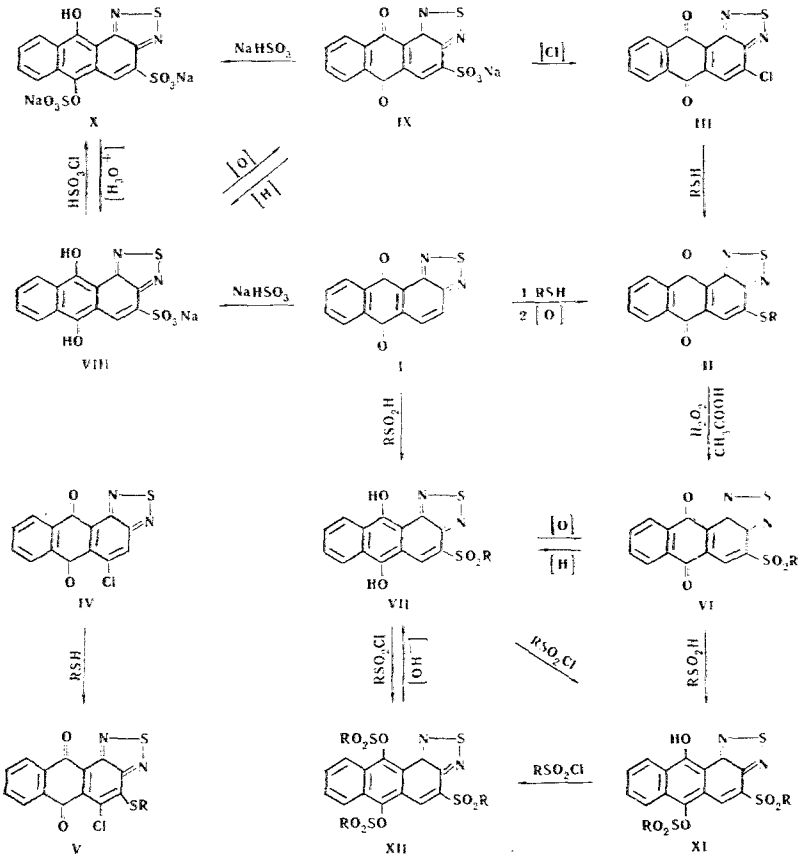
[a]Found, %: C 64.14, 64.35; H 3.04, 3.03. Calculated, %: C 64.15; H 2.70. [b]Found, %: Cl 22.24, 22.15. Calculated, %: Cl 22.26. [c]Found, %: Br 16.21, 16.17; Calculated, %: 16.47.

In an aqueous solution of sodium bisulfite, the anthraquinonethiadiazole I is converted into the anthrahydroquinone-4-sulfonic acid (VIII), and this by oxidation with chromic or nitric acid into the quinone-4-sulfonic acid (IX). The position of the sulfo group is shown by the conversion of the sulfonic acid IX into 4-chloroanthraquinonethiadiazole (III) in a yield of 90% on being boiled with potassium chlorate in hydrochloric acid solution.

As can be seen from Fig. 1, such substituents in position 4 of the nucleus as sulfo and arylsulfonyl groups have little effect on the nature of the absorption of anthraquinonethiadiazole [1]. An arylthio group has a greater effect, causing the appearance of a new maximum in the visible region at about 460 nm. In the IR spectra of the quinones II, IV, and IX, there is one strong band of carbonyl stretching vibrations in the narrow range 1667–1674 cm^{-1} (Fig. 2)

of the reaction products lack the carbonyl band and have absorption in the region of the stretching vibrations of hydroxy groups (for **XI**, 3235 cm^{-1}). The spectrum of compound **XI** has, in addition to the band of the sulfone group at 1150 cm^{-1}, a strong band at 1193 cm^{-1} which can be assigned to the symmetrical vibrations of the SO_2 group of the benzenesulfonate [2].

A proof of the structure of the product of the addition of benzenesulfonic acid to the quinone VIa is the formation of the identical substance by the acylation of the 4-phenylsulfonylhydroquinone (VII) with an equimolar amount of benzenesulfonyl chloride. In the presence of an excess of the acylating agent both the addition product XI and the hydroquinone VII are converted into the diester **XII**. The action of chlorosulfonic acid in pyridine on the hydroquinone-4-sulfonic acid **VIII** gives the same sulfuric acid monoester X as is obtained by the reaction of the quinonesulfonic acid IX



R = C_6H_5 (for II and VI R see table, also)

A noteworthy feature of the 4-arylsulfonylanthraquinonethiadiazoles (VI) and of anthraquinonethiadiazole-4-sulfonic acid (IX) consists in their capacity for adding another molecule of a nucleophilic agent. Thus, the sulfonic acid IX rapidly dissolves on heating with bisulfite to form copound **X**, and the sulfone **VIa**, on being boiled with benzenesulfonic acid in acetic acid, gives the sparingly soluble substance **XI**. The electronic spectra of the addition products differ considerably from the spectra of the initial quinones by the general nature of the curve and by the presence of a maximum at about 430 nm (Fig. 1). The IR spectra

with bisulfite. Taking steric factors into account, it may be assumed that the ester grouping is remote from the heterocycle and is therefore less hindered than position 6.

Thus, when addition to position 4 of the anthraquinonethiadiazole nucleus is impossible, such nucleophilic agents as bisulfite and arylsulfinic acids add to the carbonyl oxygen atom with the formation of monoesters of the corresponding anthrahydroquinones. This reaction, which is also characteristic of anthra [1,2-c]-1,2,5-oxadiazole-6,11-diones [3] has not been observed previously in the anthraquinone series. Fur-

ther studies are necessary to explain the reasons for the anomalous reactivity of the anthraquinonediazoles with respect to nucleophilic agents.

Addition in position 4 of anthraquinonethiadiazole, which is conjugated with the carbonyl group, can be carried out because of the electrophilic nature of the heterocycle, leading to a disturbance in the equivalence of the bonds in the adjacent benzene ring [1], but such an approach is inadequate to explain the addition to the oxygen atoms. In the literature there are isolated examples of addition to the oxygen of the CO groups of quinones which are unusual for carbonyl compounds. Among the cases described may be mentioned the addition of triphenylphosphine to p-benzoquinone [4] and tetrachloro-o-benzoquinone [5], and the addition to the latter of benzenesulfinic acid [6], certain dienes [7, 8], and diazoalkanes [9]. Although the authors [8, 9] assume a polar mechanism to be the most probable in these cases, it cannot be regarded as having been shown definitively. It is known that addition to the oxygen atoms of quinones also takes place in photochemical reactions [10–12] having a radical nature.

EXPERIMENTAL

Reaction of anthra[1,2-c]-1,2,5-thiadiazole-6,11-diones with mercaptans. a) A solution of 2.66 g (0.01 mole) of I and 0.02 mole of a mercaptan in 80 ml of dimethylformamide was boiled for 5 min and then 25 ml of a 40% solution of ferric chloride was added and the mixture was boiled for another 5 min. After cooling, the precipitate of the sulfide II was separated off and was recrystallized from acetic acid of dioxane (table). Alcoholic solutions of the sulfides fluoresce orange in UV light.

Similarly, 3.01 g (0.01 mole) of IV and 2.20 g of thiophenol gave 3.92 g (90%) of the 5-chloro-4-phenylthio derivative (V). Orange plates (from acetic acid), mp 224–225° C. Found, %: Cl 8.38, 8.52. Calculated for $C_{20}H_9ClN_2O_2S_2$, %: Cl 8.67.

b) A solution of 3.01 g (0.01 mole) of III and 1.65 g (0.015 mole) of thiophenol in 120 ml of dimethylformamide was boiled for 5 min, and 60 ml of water was added. The precipitate was filtered off, washed with ethanol, and crystallized from acetic acid. The yield of IIa was 3.10 g (83%) mp 270–271° C; a mixture with the sample obtained in experiment (a) had mp 269.5–270.5° C; the samples were also identical in respect of their UV and IR spectra.

4-Arylsulfonylanthra[1,2-c]-1,2,5-thiadiazole-6,11-diones (VI). a) At 100° C, a solution of 0.02 mole of a sodium arylsulfinate in 7 ml of water was added to a solution of 0.01 mole of I in 130 ml of acetic acid and the mixture was boiled for 1 hr 30 min. After cooling, the precipitate of the hydroquinone **VII** was filtered off and dissolved in 65 ml of dimethylformamide; 30 ml of 40% ferric chloride solution was added and the mixture was boiled for 5 min. After cooling, the quinone **VI** that had deposited was separated off and was washed with water and ethanol (see table). The reaction can be carried out wholly in dimethylformamide without the isolation of the **VII**.

b) Over 15 min, 10 ml of 30% hydrogen peroxide was added to a boiling solution of 0.001 mole of the sulfide II in 80 ml of acetic acid. After boiling for another 10 min and the distillation of half the solvent, the light yellow precipitate was separated off and recrystallized from acetic acid (table, examples **VIa, d**). The sulfide IIa gave a substance with mp 311–312° C showing no depression of the melting point in admixture with the sulfone **VIa** and identical with it in respect of its IR and UV spectra.

4-Phenylsulfonyl-6,11-dihydroxyanthra[1,2-c]-1,2,5-thiadiazole (VII). A solution of 4 g of stannous chloride in 10 ml of concentrated hydrochloric acid was added to a solution of 2.04 g (0.005 mole) of VIa in 300 ml of acetic acid at 100° C. After 20 min boiling and the distillation off of 200 ml of the solvent, 1.49 g (73%) of the leuco compound VII was obtained. Elongated orange prisms (from acetic acid with the addition of stannous chloride), mp 252–253° C. A mixture with the sample obtained from I and sodium benzenesulfinate in acetic acid (see above) showed no depression of the melting point. On oxidation with ferric chloride or nitrous acid, the substance was converted into **VIa**. Found, %: C 58.74, 58.97; H 2.84, 2.68; N 7.03, 7.06; S 15.49, 15.33. Calculated for $C_{26}H_{12}N_2O_4S_2$, %: C 58.82; H 2.96; N 6.86; S 15.70.

Benzenesulfonic acid monoester of 6,11-dihydroxy-4-phenylsulfonylanthra[1,2-c]-1,2,5-thiadiazole (XI). a) A solution of 2.04 g (0.005 mole) of **VIa** in 500 ml of acetic acid, mixed with a solution of 4.5 g (0.022 mole) of sodium benzenesulfinate in 10 ml of water, was boiled for 8 hr and filtered hot, the precipitate being washed with boiling acetic acid. This gave 0.89 g of yellow prisms of the monoester **XI** with mp 266–267° C. The bulk of the acetic acid was distilled off from the filtrate, and after dilution with water 1.16 g of a mixture of **XI** with the initial quinone was obtained. The latter was separated by passing a solution of the precipitate in dioxane through a layer of alumina 1.05 g (52%). The yield of XI calculated on the VIa that had reacted amounted to 66%. The substance is very sparingly soluble in organic solvents and when caustic soda is added to a suspension of it in aqueous dioxane a red coloration appears which then changes to blue (hydrolysis). Solutions of the substance in chloroform possess a greenish yellow fluorescence under the action of UV light.

b) A mixture of 0.41 g (0.001 mole) of VII, 24 ml of pyridine, and 0.18 g (0.001 mole) of benzenesulfonyl chloride was stirred for 30 min at 20° C and filtered, and the precipitate was washed with ethanol and hot acetic acid. This yielded 0.4 g of a substance with mp 266–267° C giving no depression of the melting point in admixture with the sample synthesized in experiment (a) and identical with it in respect of its IR spectrum. Found, %: S 17.59, 17.45. Calculated for $C_{26}H_{16}N_2O_5S_3$, %: S 17.54.

Benzenesulfonic ester of 6,11-dihydroxy-4-phenylsulfonylanthra[1,2-c]-1,2,5-thiadiazole (XII). A mixture of 0.001 of mole of VII or XI 40 ml of pyridine, and 2.12 g (0.012 mole) of benzenesulfonyl chloride was stirred at 20° C for 8 hr and filtered. The filtrate was diluted with water, and the precipitate was crystallized from acetic acid. In both cases, as a mixed sample showed, one and the same substance was obtained with mp 187–188° C. Light yellow needles soluble considerably more readily than the monoester **XI** and possessing a strong pale blue fluoresence in UV light. Found, %: N 4.20, 3.91; S 18.54, 18.37. Calculated for $C_{32}H_{20}N_2O_8S_4$, %: N 4.07; S 18.62.

6,11-Dihydroxyanthra[1,2-c]-1,2,5-thiadiazole-4-sulfonic acid (VIII). A mixture of 2.66 g (0.01 mole) of **I**, 25 ml of water, 9 ml (0.04 mole) of 4.5 N sodium bisulfite solution, and 0.5 ml of pyridine was boiled for 3 hr, and 4 g of sodium chloride was added. After cooling, the orange precipitate of the sodium salt **VIII** was filtered off and was washed with 5% sodium chloride solution, ethanol, and ether; yield 3.65 g (about 90%).

b) To a solution of 0.80 g (0.002 mole) of the sodium salt of IX in 40 ml of water was added a solution of 2.20 g of stannous chloride in 5 ml of concentrated hydrochloric acid and the mixture was boiled for 5 min, after which the addition of sodium chloride gave 0.61 g (~75%) of the sodium salt **VIII**. Orange needles (from water with the addition of stannous chloride). Found, %: N 7.25, 7.31; Na 6.08, 6.19; H_2O 6.52. Calculated for $C_{14}H_7N_2NaO_5S_2 \cdot 1.5H_2O$, %: N 7.57; Na 5.80; H_2O 6.81. **Diacetyl derivative**—light yellow needles (from a mixture of dimethylformamide and acetic anhydride). Found, %: C 47.63, 47.34; H 2.73, 2.53; N 5.92, 5.78; Na 5.01, 5.34. Calculated for $C_{18}N_{11}N_2NaO_7S_2$, %: C 47.56; H 2.44; N 6.17; Na 5.06.

Anthra[1,2-c]-1,2,5-thiadiazole-6,11-dione-4-sulfonic acid (IX). A suspension of 3.97 g (0.01 mole) of **VIII** in 170 ml of water and 5 ml of concentrated hydrochloric acid was treated with 4 ml of 30% sodium nitrite solution, and the mixture was boiled for 3 min and treated with 30 ml of saturated sodium chloride solution. After cooling, the crystals of the sodium salt **IX** were washed with 5% sodium chloride solution, with water, and with ethanol; yield 3.10 g (77%). Light yellow plates (from water), sparingly soluble in the majority of organic solvents. Found, %: C 42.53, 42.69; H 2.07, 1.92; N 7.10; 7.07; H_2O 6.58, 6.44. Calculated for $C_{14}H_5N_2NaO_5S_2$, %: $S_2 \cdot 1.5H_2O$. %: C 42.53; H 2.04; N 7.07; H_2O 6.83. S-Benzylthiouronium salt-light yellow plates (from ethanol) with mp 247–248° C (decomp.) Found,

%: C 51.51, 51.37; H 3.14, 3.20; N 10.81, 10.51.
Calculated for $C_{22}H_{16}N_4O_5S_3$, %: C 51.54; H 3.15; N 10.92. **Sulfonyl chloride**—yellow plates (from a mixture of benzene and n-hexane), mp 223—224° C (decomp.). Found, %: Cl 9.49, 9.37. Calculated for $C_{14}H_5ClN_2O_4S_2$, %: Cl 9.72.

4-Chloroanthra[1,2-c]-1,2,5-thiadiazole-6,11-dione (III). Over 4 hr, 125 ml of a saturated solution of potassium chlorate was added to a solution of 1.97 g (0.005 mole) of the sodium salt IX in 55 ml of 3% hydrochloric acid at 100° C. The precipitate (1.34)g) was filtered off, washed with hot water, and recrystallized from acetic acid. The substance formed light yellow needles with mp 284—284.5° C showing no depression of the melting point in admixture with a sample of III obtained from 3-chloro-1,2-diaminoanthraquinone [1].

Sulfuric acid monoester of 6,11-dihydroxyanthra[1,2-c]-1,2,5-thiadiazole-4-sulfonic acid (X). a) A mixture of 3.95 g (0.01 mole) of IX, 5.6 ml (0.025 mole) of 4.5 N sodium bisulfite solution, and 11 ml of water was boiled for 3 hr, and 30 ml of saturated sodium chloride was added to the resulting solution. The precipitate of the sodium salt X (2.60 g) was separated off, and on being boiled with the addition of hydrochloric acid and sodium nitrate the filtrate gave 1.28 g (32%) of the initial sulfonic acid IX. The yield of the monoester X calculated on the quinonesulfonic acid IX that had reacted was 70%. Yellow needles (from aqueous ethanol), readily souble in water. On being boiled in caustic soda solution, the substance did not change but in mineral acid solution it gave the sodium salt VIII. Aqueous solution of X fluoresce orange in UV light and give a bottle-green coloration with ferric chloride solution.

b) To a mixture of 15 ml of pyridine and 1 ml of chlorosulfonic acid at 40° C was added 0.80 g of the anhydrous sodium salt VIII, the mixture was stirred at 50° C for 30 min, and after cooling, it was poured into 50 ml of 5% sodium acetate solution. After the pyridine had been driven off in vacuum, 15 ml of a saturated solution of sodium chloride was added, and the precipitate was filtered off and crystallized from aqueous ethanol. This gave 0.72 g of a substance the properties and IR and UV spectra of which were analogous to that synthesized in case (a). Found, %: C 35.88, 35.77; H 1.42, 1.50; N 6.04, 6.31; Na 8.91, 8.70; H_2O 11.50, 11.61. Calculated for $C_{14}H_6N_2Na_2O_8S_3$, %: C 35.59; H 1.28; N 5.93. Calculated for $C_{14}H_6N_2Na_2O_8S_3 \cdot 3.5H_2O$, %: Na 8.59; H_2O 11.78.

The electronic spectra were measured on an SF-4 spectrophotometer for the sulfides II in ethanol, for the sulfonic acids in water, and for the sulfones VI in chloroform; the IR spectra were measured in KBr tablets on an IKS-14 instrument.

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Scientific-Research Institute for Organic Intermediates and Dyes, Moscow