RADICAL ARYLATION OF ESTERS OF DITHIOCARBOXYLIC ACIDS

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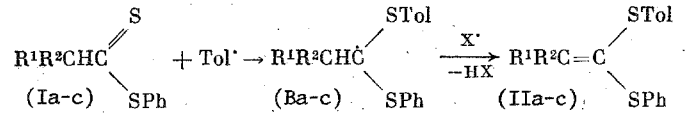
The p-tolyl radicals (Tol$^{\cdot}$), generated by the decomposition of N-nitrosoaceto-p-toluidide (NAT), are practically quantitatively trapped by phenyl dithiobenzoate to form the adduct-radicals PhC$^{\cdot}$(SPh)STol (A) [1]. Such a conclusion is made on the basis of the structure of the reaction products. Taking into account that the course of the further conversions of the adduct-radicals formed by the arylation of thiocarbonyl compounds depends significantly on the presence of readily cleaved atoms or groups in the β-position to the radical center [2], the present work investigated the interaction of the Tol$^{\cdot}$ radicals with phenyl esters of diphenyldithioacetic (Ia), phenyldithioacetic (Ib), and dithioisobutyric (Ic) acids. In contrast to phenyl dithiobenzoate, these compounds contain relatively active H atoms in the β- position to the thiocarbonyl group.

The reactions of the dithioesters (Ia-c) with NAT proceed readily with a high conversion of the initial compounds. In all cases, mixtures of products of the same type are formed. These products consist mainly of the phenyltolylmercaptals of the corresponding ketenes (IIa-c) (Table 1). The high total yields of the reaction products indicate that the ability of the thiocarbonyl group to capture the aryl radicals effectively is a general property of dithioesters. Howver, an important difference in the behavior of the compounds (Ia-c) compared to phenyl dithiobenzoate, in the reactions under consideration, is that the formed adduct-radicals (B) are mainly stabilized by the cleavage of the β-atom of H from them (Scheme 1) rather than by dimerization

Scheme 1



$R^1 = R^2 = Ph$ (a); $R^1 = Ph$, $R^2 = H$ (b); $R^1 = R^2 = Me$ (c).

It should be noted that the mercaptals $R^1R^2CHCH(SPh)STol$ are absent from the reaction products. This excludes the possibility of the formation of the products (IIa-c) on account of the disproportionation of the adduct-radicals (B). Evidently, only the cross-disproportionation takes place in these cases, i.e., the tolyl or other radicals formed in the decomposition of NAT fulfill the role of X. This was previously shown to be the case in the reactions of radical arylation of thioamides [2].

Scheme 1 is also verified since, as is apparent from Table 1, the yield of the products (IIa-c) decreases substantially in passing from (Ia) to (Ib) and (Ic). In the same series (benzhydryl, benzyl, and isopropyl), the activity of H also decreases in other radical reactions [3]. The S-phenyl (IIIa-c) and S-tolyl (IVa-c) esters of the corresponding thiolcarboxylic acids and the aromatic disulfides (V)-(VII) are formed in the reactions under consideration apart from the mercaptals of ketenes (IIa-c). The total yields of (III) and (IV), on the one hand, and of (V) and (VII), on the other hand, are thereby approximately equal in each reaction (cf. Table 1). The formation of the compounds indicated and the ratio of their yields provides a basis for the assumption that the adduct-radicals (B) also participate in the concurrent process of oxidation with the subsequent elimination of the ArS radicals from the β-position (Scheme 2) in these reactions. This was also observed previously in the arylation of phenyl dithiobenzoate [1].

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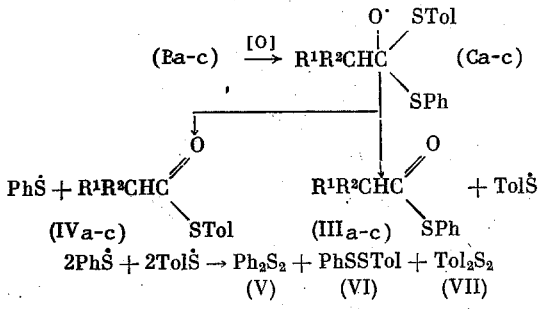
TABLE 1. Interaction of the Phenyl Esters of Dithioacids $R^1R^2CH(C=S)SPh$ (Ia-c) with N-Nitrosoaceto-p-toluidide

Compound	R^1	R^2	Conversion of (Ia-c), %	Yield of reaction products, % of theoretical					
				$R^1R^2C{=}C(STol)SPh$ (IIa-c)	$R^1R^2CHC(=O)SPh$ (IIIa-c)	$R^1R^2CHC(=O)STol$ (IVa-c)	Ph_2S_2 (V)	PhSSTol (VI)	Tol_2S_2 (VII)
(Ia)	Ph	Ph	100	75	2,1	1,2	1,2	0,6	1,0
(Ib)	Ph	H	75	39	11,0	8,0	7,0	9,0	3,0
(Ic)	Me	Me	64	34	10,0	14,0	10,0	12,0	4,0

Scheme 2



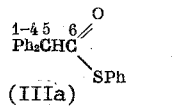
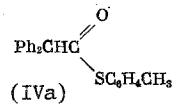
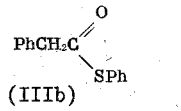
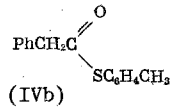
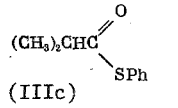
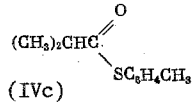
The closeness in the yields of the products (III) and (IV) in each reaction (cf. Table 1) shows that the fragmentation with the cleavage of the PhS· and TolS· radicals proceeds by approximately the same extent.

The comparison of the yields of the compounds (IIa-c), the products of the cross-disproportionation of the adduct-radicals (Ba-c), and of the compounds (III) and (IV), the products of the oxidation of the adduct-radicals (Ba-c), and their subsequent fragmentation, indicates the competition between these processes: The more difficult it is to accomplish the removal of the H atom from the radical (B) (cf. Scheme 1), the greater is the degree of its oxidation (cf. Scheme 2). A similar effect was previously observed in the arylation of thioamides [4]. It should be noted that the oxidation is the main process in the arylation of aliphatic thioamides (in particular the amides of thioisobutyric acid [4]). In the analogous reaction with the ester of dithioisobutyric acid, although the oxidation also proceeds to a significant degree, it is nevertheless not as important as the cross-disproportionation (cf. Table 1).

The structure of the compounds obtained was confirmed by the data of the PMR and mass spectra. Moreover, the ^{13}C NMR spectra of the thiol esters (IIIa-c) and the ketenemercaptals (IIa-c) were investigated (Tables 2 and 3).

As is evident from the Tables 2 and 3, a common feature of the ^{13}C NMR spectra of the compounds investigated is the presence of the signals of the phenyl, phenylthio, and tolylthio groups. The separation of the suitable signals permitted the chemical shifts (CSs) of the aromatic carbons to be taken; the known increments for the monosubstituted benzenes are not generally contradicted, assuming the additive calculation for the p-substituted ring [5]. The CSs of the C^6 atoms in the compounds (IIa) and (IIc) comprise ∿150 ppm. According to the scarce available data in the ^{13}C NMR spectra of compounds containing the ketene-S,S-acetal fragment, this value varies within very wide limits (135-185 ppm) [6, 7]. This indicates the significant sensitivity of the CS of the C^6 atom to the nature of the substituents at C^5. Neretheless, in connection with the significant difference in the magnitudes of the CSs of the C^6 atoms in compounds (IIa) and (IIc), on the one hand, and (IIb), on the other hand, (∿20 ppm), the structure of the ketenemercaptal (IIb) was confirmed by us by an independent method. With this aim, the synthesis of the compound (IId) was carried out according to the scheme:

TABLE 2. ^{13}C NMR Spectra of the Thiol Esters (IIIa, b) and (IVa, b)

Compound	δ, ppm from TMS*						
	C^1	C^2	C^3	C^4	C^5	C=O	CH_3
 (IIIa)	137,86 127,77	128,46 134,09	128,61 128,89	127,32 129,14	64,63	196,09	
 (IVa)	138,01 124,67	128,25 134,07	128,58 129,41	127,04 138,55	64,46	194,29	21,17
 (IIIb)	133,12 127,39	128,63 134,10	128,02 129,33	127,09 129,45	49,86	192,53	
 (IVb)	132,21 124,59	128,63 134,10	128,02 129,73	127,09 139,56	49,86	192,98	21,06
 (IIIc)	127,93	134,19	129,51	129,36	42,44	198,84	19,10
 (IVc)	124,51	134,19	129,36	138,29	42,55	198,42	19,10 21,03 ($CH_3C_6H_4$)

*The inverse relationship of the signals of C^2 and C^3 is possible.

$$PhCH{=}CCl_2 + PhSNa \xrightarrow{CH_3CN} PhCH{=}C(SPh)_2 (IId)$$

As is evident from Table 3, the spectral parameters of this compound, particularly the CS of the C^6 atom, agree well with the parameters found for (IIb). Therefore, these data combined with the data of the PMR and mass spectra permit the indicated structure to be assigned to the compound (IIb).

EXPERIMENTAL

The PMR and ^{13}C NMR spectra were obtained on a "Bruker WP-200-SY" spectrometer in solutions of CCl_4 and $CHCl_3$, respectively. The internal standard was TMS. The mass spectra were taken on an MS/DS-50 instrument with a direct inlet system, an entry temperature of 20°C, the temperature of the ionization chamber of 150°C, and an ionizing voltage of 70 eV. The GLC analysis was accomplished on an LKhM-80 chromatograph with a catharometer and a column 1 m × 3 mm with 5% silicone SE-30 and 6% PEG (20000) on Chromaton N-AW (0.16-0.20) in a current of He.

The separation of the products of the reaction of the dithioesters (Ia-c) with NAT was performed by column chromatography with silica gel (L 100/160) eluting sequentially with hexane and the 9:1, 5:1, and 1:1 mixtures of hexane–benzene. In the cases for which the reaction products were mixtures, their ratio was calculated from the data of the GLC and the PMR spectra. The yields of the products are given in Table 1.

S-Phenyl Esters of Thiolcarboxylic Acids $R^1R^2CHC(O)SPh$ (IIIa-c). The mixture of the acid chlorides $R^1R^2CHC(O)Cl$ (40 mmole) and an aqueous solution of PhSNa (40 mmole) was heated for 2 h at 40-45°C prior to extraction with ether. After the distillation of the solvent, (IIIa) and (IIIb) were isolated by the recrystallization of the residue from alcohol; (IIIc) was isolated by the distillation of the residue in vacuo. The yields and the constants of (IIIa-c) are presented in Table 4.

TABLE 3. ^{13}C NMR Spectra of the Ketenemercaptals

Compound	δ, ppm from TMS*						
	C^1	C^2	C^3	C^4	C^5	C^6	CH_3
(IIa)	141,95 142,01 135,21 131,21	129,48 129,41 131,60 130,58	127,54 127,94 128,76	127,14 127,11 126,11 136,04	130,16	150,61	20,93
(IIb)	137,23 136,63 134,27 133,91 131,93	129,03 132,64 131,72 131,49 130,60	127,82 129,39 129,15 128,44 128,26	127,83 126,09 126,58 135,72	136,69 136,01	129,86 130,22	21,02
PhCH=C(SPh)$_2$ (IId)	138,48 134,95 134,49	126,46 130,22 129,03	128,00 128,60 128,14	127,38 127,27 125,66	136,17	129,18	–
(IIc)	135,49 131,88	130,14 129,98	129,01 128,20	125,59 135,84	122,54	149,49	24,02 23,94 20,88 ($CH_3C_6H_4$)

*The interrelation of the signals of C^2 and C^3 is possible.

TABLE 4. S-Phenyl Esters of Thiolacids and Dithioacids $R^1R^2C(X)SPh$

Compound	R^1	R^2	X	Yield, %	bp, °C (p, mm of Hg stem) or mp, °C (from alcohol)	Found / Calculated			References
						C	H	S	
(Ia)	Ph	Ph	S	59	80	75,28 75,00	4,83 5,00	20,23 20,00	[8]
(Ib)	Ph	H	S	53	171 (1 mm)	68,61 68,85	5,16 4,91	25,86 26,22	
(Ic)	Me	Me	S	60	94 (1 mm)	61,33 61,22	6,12 6,12	32,40 32,65	[9]
(IIIa)	Ph	Ph	O	79	86	78,92 78,95	5,23 5,26	10,57 10,53	[10]
(IIIb)	Ph	H	O	75	41	73,92 74,01	4,90 4,85	14,26 14,10	[11]
(IIIc)	Me	Me	O	73	89 (2 mm)	66,58 66,67	6,53 6,67	7,89 7,78	[11]

S-p-Tolyl Ester of Diphenylthiolacetic Acid (IVa). This was obtained from diphenylacetyl chloride and p-thiocresol analogously to the description above with a yield of 76% and mp 98°C (from alcohol). Found: C 79.05, H 5.51, and S 10.31%. $C_{21}H_{18}OS$. Calculated: C 79.25, H 5.66, and S 10.06%.

Phenyl Esters of Dithiocarboxylic Acids $R^1R^2CHC(S)SPh$ (Ia-c). The experiments were performed analogously to [1]. The phenyl esters of dithiocarboxylic acids (Ia-c) were obtained from the phenyl esters of thiolcarboxylic acids (IIIa-c) and p-methoxyphenylthionophosphinesulfide. The purification was carried out on a column with silica gel (L 100/160) with the eluent as the 10:1 mixture of hexane:benzene (cf. Table 4).

Reaction of the Phenyl Ester of Diphenyldithioacetic Acid (Ia) with NAT. The solution of 2.5 g of (Ia) and 1.6 g of NAT in 40 ml of acetone was stirred for 20 h at 20°C. After the distillation of the solvent and the chromatography of the residue on a column with silica gel, the following products were obtained (in the order of washing out): 1) the mixture of the disulfides (V)-(VII) (0.1 g) and 2) the phenyl tolyl mercaptal of diphenylketene (IIa) (2.4 g) with mp 82°C (from alcohol). Found: C 78.92, H 5.39, and S 15.58%. $C_{27}H_{22}S_2$. Calculated: C 79.02, H 5.37, and S 15.61%. The PMR spectrum (δ, ppm): 2.2 singlet (3H, CH_3) and 6.8=7.3 multiplet (14H, H aromatic). The mass spectrum: (m/z): 410 (47.7%) M^+, 301 (42.9%) M^+ – SPh, 287 (63.3%) M^+ – STol, 178 (47.4%) M^+ – SPh – STol, 123 (3.7%) STol,

and 109 (4.2%) SPh, 3). The mixture of the S-phenyl (IIIa) and S-tolyl (IVa) esters of diphenylthiolacetic acid, identified by the method of GLC conforming to known standards.

Reaction of the Phenyl Ester of Phenyldithioacetic Acid (Id) with NAT. The reaction was performed as described above with 2.5 g of (Ib) and 1.9 g of NAT. After the chromatography of the reaction mass on a column with silica gel, the following products were obtained (in the order of washing out): 1) the mixture of the disulfides (V)-(VII) (0.3 g); 2) the phenyl tolyl mercaptal of phenylketene (IIb) (1.3 g). Found: C 74.89, H 5.33, and S 19.48%. $C_{21}H_{18}S_2$. Calculated: C 75.45, H 5.39, and S 19.16. The PMR spectrum (δ, ppm): 2.16 singlet (3H) and 2.19 singlet (3H, CH_3 protons of the E- and Z-form), and 6.7-7.6 multiplet (15H, H aromatic and CH=). The mass spectrum (m/z): 334 (82%) M^+, 225 (80%) M^+ –SPh, 211 (100%) M^+ – STol, 123 (17%) STol, 109 (29%) SPh, and 102 (11%) M^+ – SPh – STol; 3) the initial (Ib) (0.6 g); 4) the mixture of the S-phenyl (IIIb) and S-toly (IVb) esters of phenylthiolacetic acid (0.45 g). The PMR spectrum (δ, ppm): 2.26 singlet (CH_3), 3.75 singlet and 3.74 singlet CH_2, and 7.1-7.4 multiplet (H aromatic protons). The ratio of (IIIb) to to (IVb) was 5.5:4.3.

Reaction of the Phenyl Ester of Dithioisobutyric Acid (Ic) with NAT. The reaction was performed analogously with 2.5 g of (Ic) and 2.5 g of NAT. After the chromatography of the reaction mass on a column with silica gel, the following products were obtained (in the order of washing out): 1) the mixture of the disulfides (V)-(VII) (0.24 g); 2) the initial (Ic) (0.7 g); 3) the phenyl tolyl mercaptal of dimethylketene (IIc) (1.0 g). Found: C 70.87, H 6.53, and S 22.52%. $C_{17}H_{18}S_2$. Calculated: C 71.28, H 6.33, and S 22.39%. The PMR spectrum (δ, ppm): 2.13 singlet (3H) and 2.16 singlet ($(CH_3)_2C=$), 2.19 broad singlet (3H, CH_3–C_6H_4), and 6.7-7.2 multiplet (9H, H aromatic). The mass spectrum (m/z): 286 (100%) M^+, 177 (51%) M^+ – SPh, 163 (60%) M^+ – STol, 123 (24%) STol, and 109 (30%) SPh; 4) The mixture of the S-phenyl (IIIc) and S-tolyl (IVc) esters of thiolisobutyric acid (0.6 g). The PMR spectrum (δ, ppm): 1.22-1.24 doublets [6H, i-CH_3 of (IIIc) and (IVc)], 2.37 singlet [3H, CH_3–C_6H_4 (IVc)], 2.85 septet [CH of (IIIc) and (IVc)], and 7.3-7.9 multiplet (H aromatic). The ratio of (IIIc) to (IVc) was 2:3.

Diphenylmercaptal of Phenylketene (IId). This was obtained by a method analogous to [12]. To the suspension of PhSNa (40 mmole) in 80 ml of dry CH_3CN was added $PhCH=CCl_2$ (20 mmole) in 20 ml of CH_3CN in a current of N_2. The mixture was boiled for 3 h. The mixture was filtered, and the CH_3CN was distilled. The residue was chromatographed on a column with silica gel (L 100/160). We obtained 3.3 g (50%) of (IId). Found: C 75.04, H 5.06, and S 19.96%. $C_{20}H_{16}S_2$. Calculated: C 75.00, H 5.00, and S 20.00%.

CONCLUSIONS

1. The interaction of N-nitrosoaceto-p-toluidide (NAT) with the phenyl esters of diphenyldithioacetic, phenyldithioacetic, and dithioisobutyric acids proceeds with the practically complete addition of the generated tolyl radicals to the thiocarbonyl group of the compounds indicated.

2. The main products of the reactions under consideration are the phenyl tolyl mercaptals of the corresponding ketenes and also the S-phenyl and the S-tolyl esters of the corresponding thiol acids and the diaryldisulfides. The formation of these products is explained by the competition of different routes for the stabilization of the adduct-radicals $R^1R^2CHC^{\cdot}(SPh)STol$ which are formed as intermediates in the arylation.

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REACTION OF 6-SULFONYL-2,3-DICHLORO-1,4-NAPHTHAQUINONES WITH NUCLEOPHILIC REAGENTS

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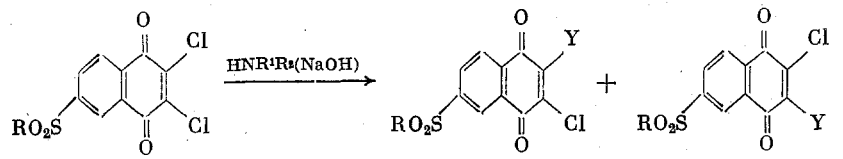
UDC 542.958.3:547.655.6

In continuation of a search for synthetic routes to water-soluble 2-dialkylaminonaphthoquinones, which are used as the light-sensitive components in nonsilver photographic processes [1, 2], we here report the reaction of some 6-sulfonyl-2,3-dichloro-1,4-naphthoquinones previously obtained by us [3] with nucleophilic reagents. There have been few reports in the literature on the reactions of nucleophiles with 6-substituted-2,3-dichloro-1,4-naphthoquinones. Naphthaquinones with electron donor substituents in the 6-position react with aniline to give mainly the 2-anilino-derivatives [4-6], and 2,3-dichloro-1,4-naphthaquinones with a sulfo- [7] or a nitro-group [5] in the 6-position react with aniline to give chlorine monosubstitution products, the structures of which were not established. Neither these reports, nor theoretical considerations concerning the regioselectivity of nucleophilic addition and substitution in naphthoquinones [8], lead to any clear conclusions as to the site of attack of nucleophiles in 1,4-naphthoquinones with electron-donor substituents in the 6-position. We here examine the structures and isomer ratios of the substitution products of 6-sulfonyl-2,3-dichloro-1,4-naphthoquinones.

As would be expected, all the 6-sulfonyl derivatives reacted readily with nucleophiles. For instance, the sodium salt of 2,3-dichloro-1,4-naphthoquinone-6-sulfonic acid (I) reacts with aliphatic amines (morpholine, cyclohexylamine, dimethylamine), 25% aqueous ammonia, and caustic alkali under mild conditions to give monochloro-substituted products which, with the exception of the 3-morpholino-compound (II), are mixtures of the 2- and 3-isomers (IIIa-c)–(VIa, b) in the proportions 1:2, 1:1, 1:5, and 1:2 respectively, according to their PMR spectra (Table 1).* Reaction of the sodium salt of the sulfonic acid (I) with sodium azide results in the replacement of both chlorines to give sodium 2,3-diazido-1,4-naphthaquinone-6-sulfonate (VII).



(I), (VIII)–(X) (IIIa)–(VIa), (XIIa)–(XVa) (II), (IIIb)–(VIb), (XIIb)–(XVb)

R = ONa (I); R = ONa, Y = N(CH₂CH₂)₂O (II); R = ONa, Y = NHC₆H₁₁ (IIIa, b); R = ONa, Y = N(CH₃)₂ (IVa, b); R = ONa, Y = NH₂ (Va, b); R = ONa, Y = OH (VIa, b); R = Cl (VIII); R = NH₂ (IX); R = N(CH₂CH₂)₂O (X); R = Y = NH₂ (XIa, b); R = Y = N(CH₂CH₂)₂O (XIIa, b); R = NH₂, Y = N(CH₂CH₂)₂O (XIIIa, a); R = N(CH₂CH₂)₂O, Y = NH₂ (XIVa, b); R = N(CH₂CH₂)₂O, Y = OH (XVa, b).

The presence of chlorine atoms in the quinone ring and of a chlorosulfonyl group is responsible for the dual reactivity of 2,3-dichloro-1,4-naphthaquinone-6-sulfonyl chloride (VIII). On heating in water with the addition of sodium carbonate, or treatment with caustic alkali at ∿20°C results both in hydrolysis of the sulfonyl chloride group and replacement of one of the chlorines in the quinone ring by hydroxy to give a mixture of isomeric hydroxychlorosulfonic acids (VIa, b). Reaction of the sulfonyl chloride (VIII) with an

*Neither TLC in a variety of systems, nor the IR spectra revealed the presence of mixtures of the 2- and 3-isomers (a and b), as opposed to a single compound.

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