Unusual oxidative dehydration of *vic*-[alkyl(aryl)thio]-substituted aromatic (heteroaromatic) carboxamides

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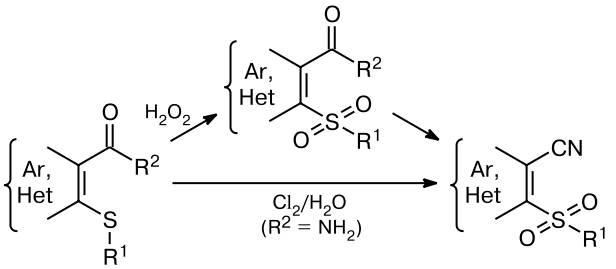
A new procedure was developed for the synthesis of nitriles of *vic*-[alkyl(aryl)sulfonyl] derivatives of benzoic, anthraquinonecarboxylic, and 4-isothiazolecarboxylic acids by the reactions of the corresponding *vic*-[alkyl(aryl)thio]-substituted aromatic (heteroaromatic) carboxamides with chlorine in organic solvents containing 20—65% of water. Oxidative dehydration of 1-(butylthio)anthraquinone-2-carboxamide afforded 1-butyl-6,11-dihydro-3*H*-1λ^4-anthra[2,1-*d*]isothiazole-3,6,11-trione 1-oxide as a by-product. The structure of the latter was established by X-ray diffraction analysis. The reaction scheme involving the formation of *S*-chlorosulfonium chlorides followed by their hydrolysis was proposed.

Key words: *vic*-[alkyl(aryl)thio]arenecarboxamides, *vic*-[alkyl(aryl)sulfonyl]arenecarbonitriles, sulfoximides, oxidative dehydration.

vic-[Alkyl(aryl)sulfonyl]-substituted aromatic (heteroaromatic) carbonitriles (**1**) are valuable intermediates for the preparation of sulfur-containing fused heterocycles, in particular, by the Thorpe reaction.[1] Generally, compounds **1** are synthesized from readily available aromatic (heteroaromatic) carboxylic acid derivatives (esters **2** or amides **3**) containing the vicinal alkyl- or arylthio group by oxidation of the S atom in compounds **2** or **3** with H_2O_2 [2] followed by the transformation of the ester or amide group into the nitrile fragment[3] (Scheme 1).

Scheme 1



2: $R^2 = OR^3$
3: $R^2 = NH_2$

1

We found that *vic*-[alkyl(aryl)thio]arenecarboxamides **3** can be transformed into nitriles **1** in one step under the action of chlorine in organic solvents containing water.

We studied this reaction for derivatives of benzamide (**4a—f**), anthraquinone-2-carboxamide (**5a—d**), and isothiazole-4-carboxamide (**6a—e**) using AcOH, CF_3COOH, DMF, and the ionic liquid 1-butyl-3-methylimidazolium tetrafluoroborate [bmim][BF_4] as the solvents. The water content was varied from 20 to 65% (v/v).

In all cases, the corresponding *vic*-[alkyl(aryl)sulfonyl]arenecarbonitriles **7—9** were isolated as the major reaction products in 35—84% yields (Scheme 2).

In the case of 3,5-bis(methylthio)isothiazole-4-carboxamide (**6e**), both alkylthio groups were oxidized to give bis-sulfone **9e**.

Oxidative dehydration of anthraquinonecarboxamides **5a—d** afforded nitriles **8a—d** along with by-products, which have virtually identical chromatographic mobilities (R_f = 0.33—0.38, SiO_2; ethyl acetate—toluene, 1 : 4) irrespective of the nature of the substituent R^1 and are, presumably, of similar chemical nature. These by-products are unstable under conditions of chromatography on silica gel, which did not allow us to isolate all compounds of this type in pure state. Nevertheless, we succeeded in isolating the by-product of oxidative dehydration of amide **5c** ($R^1 = Bu^n$), *viz.*, compound **10**, in low yield (~3%) and established its structure. Cyclic sulfoximides containing the S and N atoms in the five-membered heterocyclic ring are known in the 3-oxobenzo[*d*]isothiazole series.[4,5] Compound **10** is, to our knowledge, the first representative of fused sulfoximides of the anthraquinoneisothiazole series.

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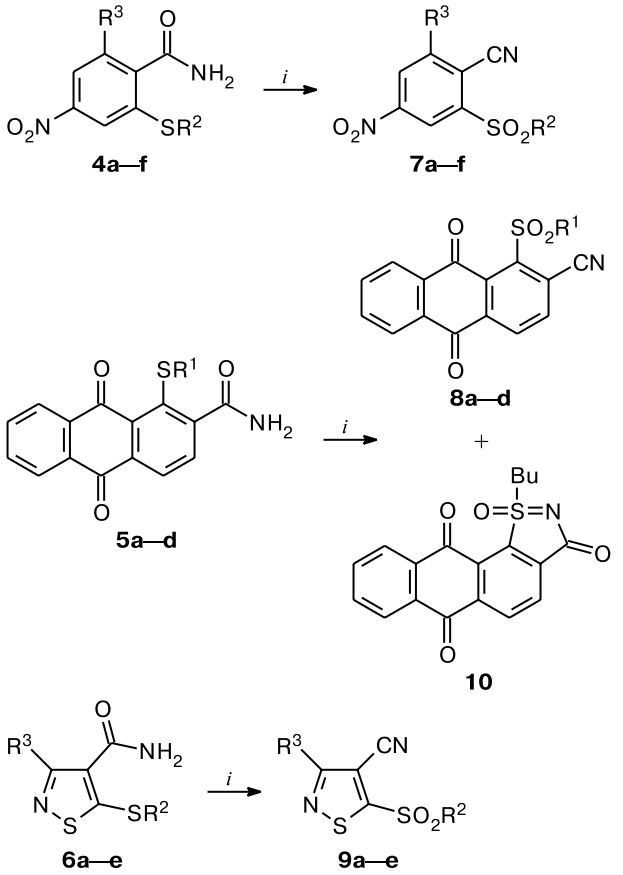
Scheme 2



Compound	R^2	R^3	Compound	R^1	Compound	R^2	R^3
4, **7**			**5**, **8**		**6**, **9**		
a	Et	H	**a**	Me	**a**	Me	OMe
b	Pr^n	H	**b**	Et	**b**	Me	Cl
c	n-C_8H_{17}	H	**c**	Bu^n	**c**	Bu^n	OMe
d	Ph	H	**d**	Ph	**d**	Me	Ph
e		H			**e**	Me	SMe (**6**),
f	Ph	NO_2					SO_2Me (**9**)

Reagents and conditions: *i*. Cl_2, organic solvent—water.

The **8c** : **10** ratio (Table 1), which was determined from the integral intensity ratio of the signals for the SCH_2 protons in the ^1H NMR spectrum of the crude product, depends on the solvent used. The percentage of heterocycle **10** increases in the series of DMF, [bmim][BF_4], and CF_3COOH in parallel with the increase in their polarity characterized by the Dimroth—Reichardt $E_T(30)$ parameter.[6]

The percentage of sulfoximide **10** produced in the reaction in aqueous DMF slightly increases as the water content increases ($E_T(30)_{H_2O}$ = 63.1 kcal mol^{-1}),[8] which also indicates that the polar reaction medium has a favorable effect on heterocyclization.

Table 1. Yields and ratios of products **8c** and **10** prepared by oxidative dehydration of amide **5c** in various solvents

Solvent	$E_T(30)$ /kcal mol^{-1}	Percentage of H_2O	Total yield of **8c** and **10**	**8c** : **10**
			%	
DMF	43.2 [6]	50	62	3 : 1
DMF	43.2 [6]	65	57	2 : 1
[bmim][BF_4]	52.5 [7]	20	80	1 : 1
CF_3COOH	~59*	50	86	1 : 1

* We did not find the experimental value of $E_T(30)$ for CF_3COOH in chemical literature. The value given in Table 1 was estimated by comparing $E_T(30)$ for $MeCH_2OH$ (51.9), CF_3CH_2OH (59.8), and MeCOOH (51.7).[6]

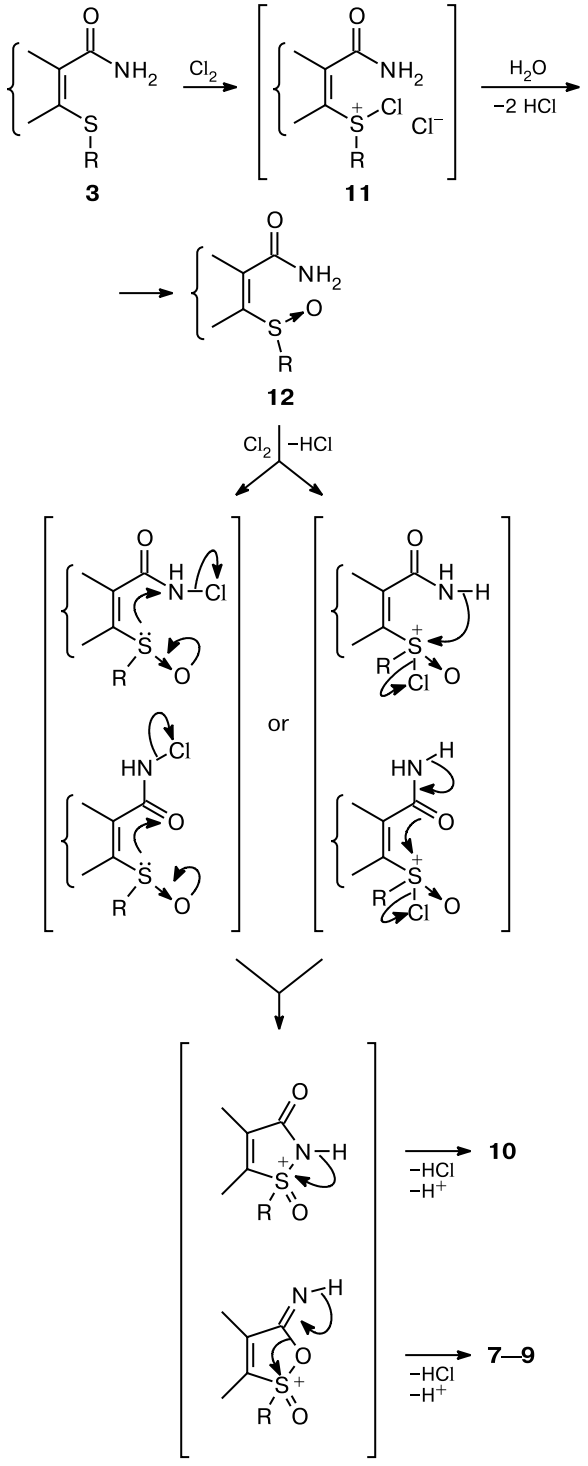
Oxidative dehydration of *vic*-[alkyl(aryl)thio]-substituted aromatic (heteroaromatic) carboxamides **4**—**6** with chlorine in aqueous organic solvents proceeds apparently through the formation of *S*-chlorosulfonium chlorides (**11**) followed by their hydrolysis. This assumption is consistent with the known data on the formation of sulfoxides in the reactions of sulfides with chlorinating agents (Cl_2,[9,10] NCS,[11] trichloroisocyanuric acid[12]) in the presence of water. Sulfoxides **12** thus formed undergo subsequent chlorination at the N or S atom to form intermediates which are transformed into the final reaction products through deprotonation and (or) elimination of HCl (Scheme 3). Based on the available experimental data, it is impossible to unambiguously choose one particular direction of chlorination. However, these data demonstrate that the amide group can sometimes exhibit dual reactivity in the reaction under consideration and react with the vicinal sulfoxide group with involvement of either the O or N atom to give nitriles **7**—**9** or sulfoximides **10**, respectively, as the final products.

This reaction scheme was confirmed by the synthesis of products **7a**—**d**,**g**,**h** from sulfoxides **12a**—**d**,**g**,**h**, which were prepared by the independent method (oxidation of sulfides **4** with hydrogen peroxide), under the action of chlorine.* This transformation proceeds smoothly both in the presence of water and under anhydrous conditions, which is evidence for the intramolecular character of oxidation of the S atom (Scheme 4).

The elucidation of the structures of reaction products **7**—**10** requires additional comments. Recently,[15] we have erroneously assigned the structures of isomeric fused

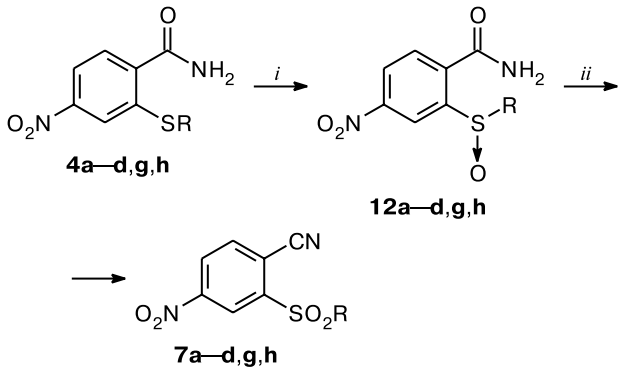
* The structures of compounds **12a**—**c**,**g** as *S*-oxides were proved by the fact that the ^1H NMR spectra of these compounds show nonequivalent signals for the diastereotopic protons of the methylene group bound to the S atom (Table 2). The structures of compounds **12d**,**h** were confirmed by the presence of a molecular ion peak in their mass spectra (Table 3).

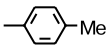
Scheme 3



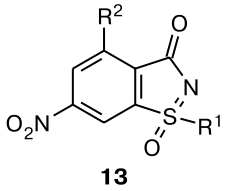
sulfoximines **13** to compounds **7a**—**d**,**f** based on the results of IR and ^{1}H NMR spectroscopy, mass spectrometry, and elemental analysis. The erroneous interpretation of the experimental data resulted primarily from the very low intensity of the signal of the C≡N group in the IR

Scheme 4



Compound	R	Yield (%)	
4, **7**, **12**		**12**	**7**
a	Et	96	96
b	Pr	81	82
c	n-C_8H_{17}	90	84
d	Ph	91	86
g	Bu^n	81	82
h		82	79

Reagents and conditions: *i*. H_2O_2, AcOH; *ii*. Cl_2, AcOH.

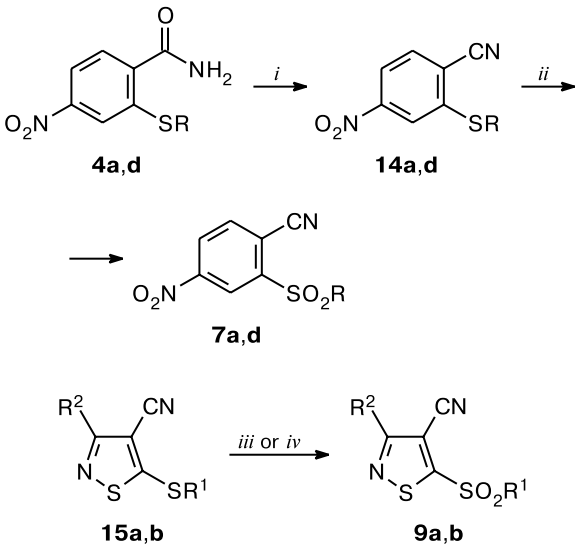


spectra of these compounds, which is comparable with the intensity of the noise signals. The true structures of compounds **7**—**10** were established by chemical methods and X-ray diffraction analysis. For example, oxidative dehydration products **7a**,**d** and **9a**,**b** are identical to compounds prepared independently from nitriles **14a**,**d** and **15a**,**b**, respectively, under the action of 30% H_2O_2 in AcOH or *m*-CPBA in CH_2Cl_2 (Scheme 5). The structure of compounds **9c,e**, whose melting points differ substantially from that published in the literature, were confirmed by the results of ^{1}H NMR spectroscopy, mass spectrometry, and elemental analysis (see Tables 2 and 3).

The structure of compound **8d**, whose independent synthesis is difficult to perform because the corresponding nitrile is hardly accessible, and the structure of sulfoximide **10** were unambiguously established by X-ray diffraction analysis (Figs. 1 and 2, respectively).

To summarize, we developed a convenient one-pot synthesis of *vic*-[alkyl(aryl)sulfonyl]-substituted aromatic (heteroaromatic) carbonitriles by oxidative dehydration of *vic*-[alkyl(aryl)thio]-substituted aromatic (heteroaromatic) carboxamides with chlorine in organic solvents

Scheme 5



Compound	R	Yield (%)		Compound	R^1	R^2	Yield
		14	**7**				**9** (%)
4, **7**, **14**				**9**, **15**			
a	Et	97	86	**a**	Me	OMe	40
d	Ph	89	80	**b**	Me	Cl	52

Reagents and conditions: *i*. $POCl_3$; *ii*. H_2O_2; AcOH; *iii*. H_2O_2, AcOH (**15a**); *iv*. *m*-Chloroperoxybenzoic acid, CH_2Cl_2 (**15b**).

containing 20—65% of water and synthesized the first representative of fused sulfoximides of the anthraisothiazole series.

Experimental

The ^{1}H NMR spectra were recorded on a Bruker AM-300 spectrometer (300.13 MHz) in DMSO-d_6. The chemical shifts were measured relative to Me_4Si as the internal standard. The mass spectra were obtained on an MS-30 instrument (Kratos) in the electron impact mode (70 eV). The TLC analysis was carried out on Silufol UV-250 plates in a 1 : 4 ethyl acetate—toluene system. Compounds **4a**—**f**,[15] **5a**—**d**,[16] **6e**, and **15a**,**b** [14,17] were synthesized according to procedures published in the literature. Compounds **6a**—**d** were prepared for the first time according to a procedure described earlier.[14] The solvents were purified using standard procedures.[18] The ionic liquid [bmim][BF_4] was prepared according to a known procedure.[19]

The yields, melting points, ^{1}H NMR spectroscopic data, and the results of elemental analysis for the compounds synthesized are given in Table 2. The mass-spectrometric characteristics of compounds **9a**—**e** are listed in Table 3.

Single crystals of compounds **8c** and **10** suitable for X-ray diffraction analysis were prepared by crystallization from a 4 : 1 toluene—ethyl acetate system. The crystallographic data and the main details of structure refinement are given in Table 4. The X-ray diffraction data for compound **8c** were collected on a Bruker SMART CCD-1000 diffractometer equipped with a two-coordinate detector (Mo-Kα radiation, λ = 0.71073 Å, ω scan-

Table 2. Yields, melting points, results of microanalysis, and ^{1}H NMR spectroscopic data for the compounds synthesized

Compound	Yield (%)	M.p. /°C	Found / Calculated (%)				Molecular formula	^{1}H NMR (δ, *J*/Hz)
			C	H	N	S		
6a	66	156—160	35.33 35.28	4.03 3.95	13.70 13.71	31.27 31.40	$C_6H_8N_2O_2S_2$	3.20 (s, 3 H, OMe); 4.01 (s, 3 H, SMe); 7.05, 7.35 (both br.s, 1 H each, NH)
6b	58	145—147	28.61 28.78	2.63 2.41	13.12 13.42	30.91 30.73	$C_5H_5ClN_2OS_2$	2.61 (s, 3 H, SMe); 7.70, 7.83 (both br.s, 1 H each, NH)
6c	74	173—175	43.75 43.88	5.75 5.73	11.28 11.37	26.11 26.03	$C_9H_{14}N_2O_2S_2$	0.91 (t, 3 H, $(CH_2)_3C\underline{H}_3$, *J* = 7.4); 1.43 (m, 2 H, $(CH_2)_2C\underline{H}_2Me$); 1.68 (m, 2 H, $CH_2C\underline{H}_2CH_2Me$); 2.89 (t, 2 H, $C\underline{H}_2(CH_2)_2Me$, *J* = 6.6); 3.29 (s, 3 H, OMe); 7.46, 8.23 (both br.s, 1 H each, NH)
6d	87	193—196	49.69 49.60	3.71 3.78	10.48 10.52	24.18 24.08	$C_{11}H_{10}N_2O_2S_2$	3.41 (s, 3 H, SMe); 7.36—7.50 (m, 3 H, Ph); 7.61—7.74 (m, 3 H, Ph, NH); 7.79 (br.s, 1 H, NH)
7a	68, 86*, 96**	153—154	45.12 45.00	3.38 3.36	11.60 11.66	13.28 13.35	$C_9H_8N_2O_4S$	1.22 (t, 3 H, Me, *J* = 7.0); 3.59 (q, 2 H, CH_2, *J* = 7.0); 8.50 (d, 1 H, H(6), *J* = 8.0); 8.67 (s, 1 H, H(3)); 8.71 (d, 1 H, H(5), *J* = 8.0)
7b	79, 82**	119—121	47.29 47.24	3.91 3.96	10.91 11.02	12.52 12.61	$C_{10}H_{10}N_2O_4S$	0.97 (t, 3 H, Me, *J* = 7.0); 1.69 (m, 2 H, CH_2); 3.57 (m, 2 H, SCH_2); 8.49 (d, 1 H, H(6), *J* = 8.0); 8.67 (s, 1 H, H(3)); 8.70 (d, 1 H, H(5), *J* = 8.0)
7c	65, 84**	100—102	55.62 55.54	6.20 6.21	8.76 8.64	10.11 9.88	$C_{15}H_{20}N_2O_4S$	0.85 (t, 3 H, Me, *J* = 7.0); 1.24 (m, 8 H, 4 CH_2); 1.36 (m, 2 H, Me); 1.65 (m, 2 H, CH_2); 3.57 (m, 2 H, SCH_2); 8.50 (d, 1 H, H(6), *J* = 8.0); 8.67 (s, 1 H, H(3)); 8.71 (d, 1 H, H(5), *J* = 8.0)

(*to be continued*)

Table 2 (*continued*)

Compound	Yield (%)	M.p. /°C	Found / Calculated (%) C	H	N	S	Molecular formula	^{1}H NMR (δ, *J*/Hz)
7d	71, 80*, 86**	144—147	54.35 54.16	2.89 2.80	9.53 9.72	11.19 11.12	$C_{13}H_8N_2O_4S$	7.71 (t, 2 H, *m*-Ph, *J* = 7.5), 7.82 (t, 1 H, *p*-Ph, *J* = 7.5); 8.09 (d, 2 H, *o*-Ph, *J* = 7.5); 8.42 (d, 1 H, H(6), *J* = 8.5); 8.66 (s, 1 H, H(3)); 8.89 (d, 1 H, H(5), *J* = 8.5)
7e	84	186—189	51.07 50.98	2.22 2.30	8.96 9.15	10.41 10.47	$C_{13}H_7FN_2O_4S$	7.56 (t, 2 H, CH, $J_{H,H}$ = 8.0, $J_{H,F}$ = 8.0); 8.19 (dd, 2 H, CH, $J_{H,H}$ = 8.0, $J_{H,F}$ = 4.8); 8.42 (d, 1 H, H(6), *J* = 8.2); 8.65 (d, 1 H, H(5), *J* = 8.2); 8.80 (s, 1 H, H(3))
7f	69	160—162	46.67 46.85	2.34 2.12	12.53 12.61	9.56 9.62	$C_{13}H_7N_3O_6S$	7.75 (t, 2 H, *m*-Ph, *J* = 7.5); 7.93 (d, 1 H, *p*-Ph, *J* = 7.5); 8.23 (d, 2 H, *o*-Ph, *J* = 7.5); 9.21 (s, 1 H, H(5)); 9.49 (s, 1 H, H(7))
7g	82**	110—113	49.19 49.24	4.31 4.51	10.35 10.44	11.78 11.95	$C_{11}H_{12}N_2O_4S$	0.87 (t, 3 H, Me, *J* = 7.0); 1.39, 1.64 (both m, 2 H each, CH_2); 3.59 (m, 2 H, SCH_2); 8.50 (d, 1 H, H(6), *J* = 8.0); 8.67 (s, 1 H, H(3)); 8.71 (d, 1 H, H(5), *J* = 8.0)
7h	79**	162—166	55.71 55.62	3.21 3.33	8.97 9.27	10.82 10.61	$C_{14}H_{10}N_2O_4S$	2.40 (s, 3 H, Me); 7.52, 7.97 (both d, 2 H each, CH, *J* = 8.0); 8.40 (d, 1 H, H(6), *J* = 8.0); 8.63 (d, 1 H, H(5), *J* = 8.0); 8.85 (s, 1 H, H(3))
8a	35	311—313	61.51 61.73	2.83 2.91	4.66 4.50	10.17 10.30	$C_{16}H_9NO_4S$	3.83 (s, 3 H, Me); 7.72—8.25 (m, 4 H, H(5), H(6), H(7), H(8)); 8.36—8.68 (m, 2 H, H(3), H(4))
8b	34	249—251	62.72 62.76	3.52 3.41	4.06 4.31	10.11 9.86	$C_{17}H_{11}NO_4S$	1.44 (t, 3 H, Me, *J* = 6.2); 4.07 (q, 2 H, CH_2, *J* = 6.2); 7.90—8.00 (m, 2 H, H(6), H(7)); 8.02—8.18 (m, 2 H, H(5), H(8)); 8.47, 8.56 (both d, 1 H each, H(3) or H(4), *J* = 8.3)
8c	35	201—203	64.62 64.57	4.16 4.28	4.03 3.96	9.29 9.07	$C_{19}H_{15}NO_4S$	0.93 (t, 3 H, Me, *J* = 6.2); 1.48 (m, 2 H, $(CH_2)_2C\underline{H}_2Me$); 1.86 (m, 2 H, $CH_2C\underline{H}_2CH_2Me$); 4.03 (t, 2 H, $C\underline{H}_2(CH_2)_2Me$, *J* = 6.2); 7.86—8.27 (m, 4 H, H(5), H(6), H(7), H(8)); 8.45, 8.53 (both d, 1 H each, H(3) or H(4), *J* = 7.1)
8d	39	306—308	67.79 67.55	2.81 2.97	3.93 3.75	8.52 8.59	$C_{21}H_{11}NO_4S$	7.67—8.01 (m, 5 H, H(6), H(7), Ph); 8.05—8.24 (m, 4 H, H(5), H(8), Ph); 8.50, 8.77 (both d, 1 H each, H(3) or H(4), *J* = 7.3)
9a	51, 40***	164—169 (lit. data[13]: 167—168)	33.12 33.02	2.82 2.77	12.62 12.84	29.11 29.38	$C_6H_6N_2O_3S_2$	3.59 (s, 3 H, OMe); 4.08 (s, 3 H, SO_2Me)
9b	35, 52*	139—142	26.53 26.97	1.25 1.36	12.73 12.58	29.01 28.80	$C_5H_3ClN_2O_2S_2$	3.64 (s, 3 H, SO_2Me)
9c	38	83—84 (lit. data[13]: 51—52)	41.58 41.52	4.41 4.65	10.95 10.76	24.44 24.63	$C_9H_{12}N_2O_3S_2$	0.97 (t, 3 H, $(CH_2)_3C\underline{H}_3$, *J* = 7.2); 1.50 (m, 2 H, $(CH_2)_2C\underline{H}_2Me$); 1.84 (m, 2 H, $CH_2C\underline{H}_2CH_2Me$); 3.40 (t, 2 H, $C\underline{H}_2(CH_2)_2Me$, *J* = 7.9); 4.16 (s, 3 H, Me)
9d	81	155—157	50.13 49.98	3.25 3.05	10.48 10.60	24.13 24.26	$C_{11}H_8N_2O_2S_2$	3.66 (s, 3 H, SO_2Me); 3.62 (m, 3 H, Ph); 7.94 (m, 2 H, Ph)
9e	61	240—241 (lit. data[14]: 212—214)	26.87 27.06	2.23 2.27	10.31 10.52	36.43 36.12	$C_6H_6N_2O_4S_3$	3.55, 3.70 (both s, 3 H each, Me)
10	3	246—249	64.72 64.57	4.23 4.28	3.71 3.96	9.12 9.07	$C_{19}H_{15}NO_4S$	0.80 (t, 3 H, Me, *J* = 6.2); 1.36 (m, 2 H, $(CH_2)_2C\underline{H}_2Me$); 1.86 (m, 2 H, $CH_2C\underline{H}_2CH_2Me$); 4.17, 4.29 (both m, 1 H each, $C\underline{H}_2(CH_2)_2Me$); 7.86—8.27 (m, 4 H, H(7), H(8), H(9), H(10)); 8.33, 8.66 (both d, 1 H each, H(4) or H(5), *J* = 7.5)

(*to be continued*)

Table 2 (*continued*)

Compound	Yield (%)	M.p. /°C	Found / Calculated (%)				Molecular formula	^{1}H NMR (δ, *J*/Hz)
			C	H	N	S		
12a	96	196—200	44.47 44.62	4.19 4.16	11.33 11.56	13.40 13.24	$C_9H_{10}N_2O_4S$	1.21 (t, 3 H, Me, *J* = 7.0); 2.75 and 3.26 (both m, 2 H each, CH_2S); 7.75 (s, 1 H, NH); 8.18 (d, 1 H, H(6), *J* = 8.0); 8.36 (d, 1 H, H(5), *J* = 8.0); 8.39 (s, 1 H, NH); 8.77 (s, 1 H, H(3))
12b	81	193—196	46.92 46.87	4.69 4.72	10.88 10.93	12.64 12.51	$C_{10}H_{12}N_2O_4S$	1.07 (t, 3 H, Me, *J* = 7.0); 1.66 and 1.90 (both m, 2 H each, CH_2); 2.61 and 3.24 (both m, 2 H each, CH_2S); 7.79 (s, 1 H, NH); 8.17 (d, 1 H, H(6), *J* = 8.0); 8.37 (d, 1 H, H(5), *J* = 8.0); 8.41 (s, 1 H, NH); 8.80 (s, 1 H, H(3))
12c	90	157—159	55.31 55.19	6.61 6.79	8.70 8.58	9.76 9.82	$C_{15}H_{22}N_2O_4S$	0.89 (t, 3 H, Me, *J* = 7.0); 1.31 (m, 8 H, 4 CH_2); 1.41 and 1.45 (both m, 2 H each, CH_2); 1.62 and 1.78 (both m, 2 H each, CH_2); 2.61 and 3.15 (both m, 2 H each, CH_2S); 7.69 (s, 1 H, NH); 8.17 (d, 1 H, H(6), *J* = 8.0); 8.35 (m, 2 H, H(5) + NH); 8.81 (s, 1 H, H(3))
12d	91	245—248	53.83 53.79	3.52 3.47	9.69 9.65	11.23 11.05	$C_{13}H_{10}N_2O_4S$	7.92 (m, 3 H, *p*-Ph + *m*-Ph); 7.70 (d, 2 H, *o*-Ph, *J* = 7.5); 7.86 (s, 1 H, NH); 8.08 (d, 1 H, H(6), *J* = 8.5); 8.47 (m, 2 H, H(5) + NH); 8.90 (s, 1 H, H(3))
12g	81	162—164	48.71 48.88	5.13 5.22	10.48 10.36	11.91 11.86	$C_{11}H_{14}N_2O_4S$	0.97 (t, 3 H, Me, *J* = 7.0); 1.48 (m, 2 H, CH_2); 1.60 and 1.86 (both m, 2 H each, CH_2); 2.62 and 3.27 (both m, 2 H each, CH_2S); 7.73 (s, 1 H, NH); 8.16 (d, 1 H, H(6), *J* = 8.5); 8.32 (m, 2 H, H(5) + NH); 8.80 (s, 1 H, H(3))
12h	82	276—279	55.41 55.25	4.04 3.97	9.11 9.21	10.68 10.54	$C_{14}H_{12}N_2O_4S$	2.34 (s, 3 H, Me); 7.21 (d, 2 H, CH, *J* = 8.5); 7.62 (d, 2 H, CH, *J* = 8.5); 7.72 (s, 1 H, NH); 8.09 (d, 1 H, H(6), *J* = 8.8); 8.30 (s, 1 H, NH); 8.33 (d, 1 H, H(5), *J* = 8.8); 8.91 (s, 1 H, H(3))
14a	97	131—133	52.21 51.91	3.62 3.87	13.56 13.45	15.42 15.40	$C_9H_8N_2O_2S$	1.43 (t, 3 H, Me, *J* = 6.6); 3.24 (q, 2 H, CH_2, *J* = 6.6); 8.02 (d, 1 H, H(6), *J* = 9.8); 8.08 (d, 1 H, H(5), *J* = 9.8); 8.16 (s, 1 H, H(3))
14d	89	139—142	61.19 60.92	3.01 3.15	11.14 10.93	12.20 12.51	$C_{13}H_8N_2O_2S$	7.61 (m, 3 H, *p*-Ph + *m*-Ph); 7.63 (d, 2 H, *o*-Ph, *J* = 7.5); 7.73 (s, 1 H, H(3)); 8.15 (d, 1 H, H(6), *J* = 8.3); 8.19 (d, 1 H, H(5), *J* = 8.3)

* The yields of **7a**,**d** and **9b** in the reactions of nitriles **14a**,**d** and **15b** with H_2O_2 in AcOH.
** The yields of **7a**—**d**,**g**,**h** in the reactions of sulfoxides **12a**—**d**,**g**,**h** with Cl_2 in AcOH.
*** The yield of **9a** in the reaction of nitrile **15a** with *m*-CPBA in CH_2Cl_2.

Table 3. Characteristics of the mass spectra of compounds **9a**—**e** and **12d**,**h**

Compound	MS (EI, 70 eV), *m*/*z* (I_{rel} (%))
9a	218 $[M]^+$ (61), 203 (5), 189 (14), 171 (3)
9b	224 $[M]^+$ (12), 222 $[M]^+$ (27), 207 (7), 191 (2), 175 (3)
9c	260 $[M]^+$ (7), 233 (1), 205 (4), 195 (14)
9d	264 $[M]^+$ (16), 217 (1), 200 (9)
9e	266 $[M]^+$ (10), 251 (2), 235 (1), 204 (36)
12d	290 $[M]^+$ (5), 274 (2), 213 (7), 197 (100), 167 (7), 151 (20), 125 (15), 109 (10), 77 (25)
12h	304 $[M]^+$ (4), 288 (4), 213 (3), 197 (100), 167 (5), 151 (15), 139 (35), 123 (10), 91 (20), 77 (10)

ning technique, scan step was 0.3°, frames were exposed for 10 s). The X-ray data for compound **10** were collected on a Syntex $P2_1$ diffractometer (Mo-Kα radiation, λ = 0.71073 Å). Both structures were solved by direct methods. The positions and thermal parameters of the nonhydrogen atom were refined first isotropically and then anisotropically by the full-matrix least-squares method. The H atoms in the structure of **8c** were placed in geometrically calculated positions and refined using the riding model. The H atoms in the structure of **10** were located from a difference electron density map and refined isotropically. In the structure of **8c**, the butyl group is disordered over two positions with occupancies of 0.7/0.3 (in Fig. 1, the minor component is shown by gray lines). All calculations were carried out on a personal computer using the SHELXTL program package.[20]

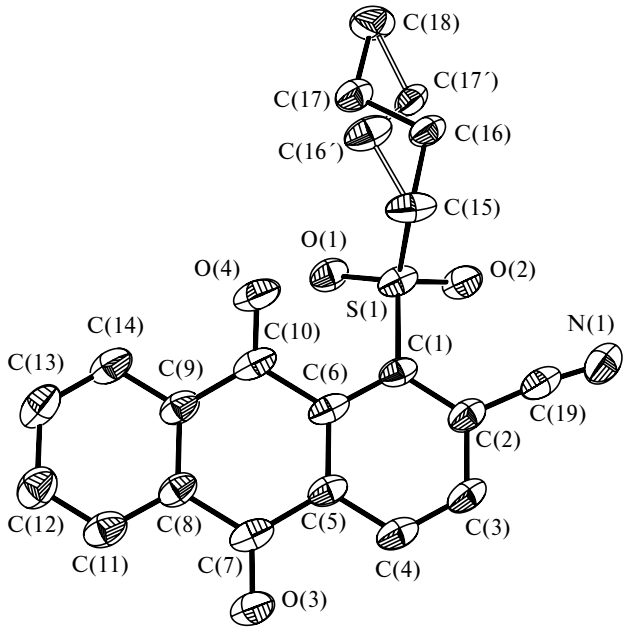


Fig. 1. General view of molecule **8c**.

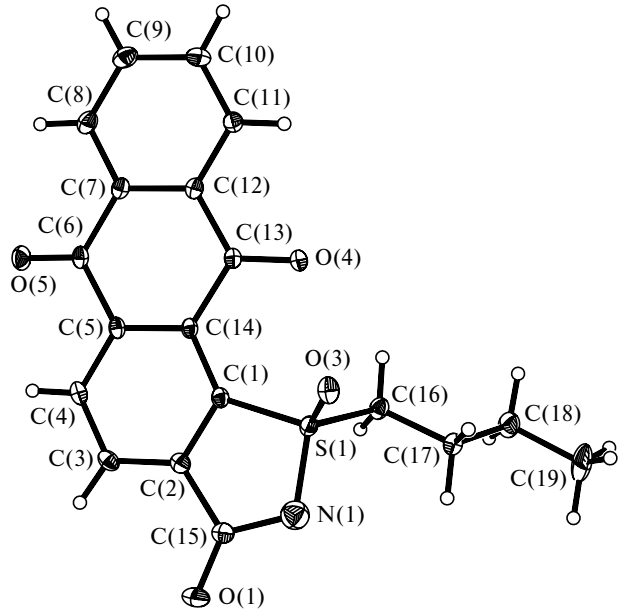


Fig. 2. General view of molecule **10**.

The atomic coordinates and thermal parameters were deposited with the Cambridge Structural Database. The bond lengths and bond angles are given in Tables 5 and 6.

Synthesis of 2-[alkyl(aryl)sulfonyl]-4-nitrobenzonitriles (7a—f) (general procedure). ***A.*** A weak stream of chlorine was passed through solutions of *vic*-alkyl(aryl)benzocarboxamides **4a—f** (2 mmol) in 60% aqueous AcOH (3 mL) at 20 °C for 10 min (TLC control). The solvent and the excess of chlorine were removed *in vacuo*. Cold water (5 mL) was added to the residue. The precipitates of **7a—f** were filtered off, dried in air, and recrystallized from Pr^iOH.

B. A 30% H_2O_2 solution (0.2 mL, 1.94 mmol) was added to a solution of nitrile **14a** (**14d**) (0.48 mmol) in AcOH (5 mL). The reaction mixture was refluxed for 2 h and the same amount of

Table 4. Crystallographic data and parameters of the structure refinement for compounds **8c** and **10**

Parameter	**8c**	**10**
Molecular formula	$C_{19}H_{15}NO_4S$	$C_{19}H_{15}NO_4S$
Molecular weight	353.38	353.38
Space group	$P2_1/c$	$P\bar{1}$
T/K	120(2)	163(2)
a/Å	12.605(1)	8.649(3)
b/Å	11.981(1)	9.320(3)
c/Å	10.7513(9)	10.272(3)
α/deg	90	82.49(2)
β/deg	100.104(2)	80.91(2)
γ/deg	90	83.36(2)
V/Å^3	1598.5(2)	806.9(4)
Z	4	2
d_{calc}/g cm^{-3}	1.468	1.455
μ/cm^{-1}	2.28	2.25
$2\theta_{max}$/deg	60	52
Number of independent reflections (R_{int})	4486 (0.0382)	2907 (0.0173)
R_1 (against F for reflections with $I > 2\sigma(I)$)	0.0621 (2151 reflections)	0.0382 (2349 reflections)
wR_2 (against F^2 for all reflections)	0.1402	0.1194
Number of parameters in refinement	249	286

Table 5. Bond lengths (d) and bond angles (ω) in the structure of **8c**

Bond	d/Å	Angle	ω/deg
S(1)—O(1)	1.426(2)	O(1)—S(1)—O(2)	118.0(1)
S(1)—O(2)	1.429(2)	O(1)—S(1)—C(15)	112.0(1)
S(1)—C(15)	1.783(3)	O(2)—S(1)—C(15)	107.5(2)
S(1)—C(1)	1.807(3)	O(1)—S(1)—C(1)	107.3(1)
O(3)—C(7)	1.220(3)	O(2)—S(1)—C(1)	105.0(1)
O(4)—C(10)	1.216(3)	C(15)—S(1)—C(1)	106.3(1)
N(1)—C(19)	1.151(4)	C(2)—C(1)—C(6)	118.6(2)
C(1)—C(2)	1.407(3)	C(2)—C(1)—S(1)	118.4(2)
C(1)—C(6)	1.408(4)	C(6)—C(1)—S(1)	121.9(2)
C(2)—C(19)	1.439(5)	C(3)—C(2)—C(1)	120.4(3)
		C(3)—C(2)—C(19)	115.6(2)
		C(1)—C(2)—C(19)	124.0(3)
		N(1)—C(19)—C(2)	171.5(3)
		C(1)—C(6)—C(10)	122.1(2)
		O(3)—C(7)—C(8)	122.3(3)
		O(3)—C(7)—C(5)	119.5(2)
		O(4)—C(10)—C(9)	121.5(3)
		O(4)—C(10)—C(6)	120.7(3)

Table 6. Bond lengths (*d*) and bond angles (ω) in the structure of **10**

Bond	*d*/Å	Angle	ω/deg
S(1)—O(3)	1.440(2)	O(3)—S(1)—N(1)	115.41(9)
S(1)—N(1)	1.573(2)	O(3)—S(1)—C(1)	114.12(9)
S(1)—C(16)	1.775(2)	O(3)—S(1)—C(16)	110.5(1)
S(1)—C(1)	1.789(2)	N(1)—S(1)—C(16)	107.4(1)
O(1)—C(15)	1.216(2)	N(1)—S(1)—C(1)	98.48(9)
N(1)—C(15)	1.376(3)	C(16)—S(1)—C(1)	110.27(9)
O(4)—C(13)	1.216(2)	C(15)—N(1)—S(1)	112.2(1)
O(5)—C(6)	1.216(2)	C(2)—C(1)—C(14)	122.2(2)
C(1)—C(2)	1.383(3)	C(2)—C(1)—S(1)	105.3(1)
C(2)—C(3)	1.391(3)	C(14)—C(1)—S(1)	132.0(2)
C(2)—C(15)	1.518(3)	C(1)—C(2)—C(3)	120.5(2)
C(13)—C(14)	1.493(3)	C(3)—C(2)—C(15)	127.1(2)
C(16)—C(17)	1.526(3)	C(4)—C(3)—C(2)	118.5(2)
C(17)—C(18)	1.520(3)	C(3)—C(4)—C(5)	121.2(2)
C(18)—C(19)	1.501(3)	C(4)—C(5)—C(14)	120.6(2)
		C(4)—C(5)—C(6)	119.0(2)
		C(14)—C(5)—C(6)	120.4(2)
		O(5)—C(6)—C(7)	121.7(2)
		O(5)—C(6)—C(5)	120.4(2)
		C(7)—C(6)—C(5)	117.9(2)
		O(4)—C(13)—C(12)	122.5(2)
		O(4)—C(13)—C(14)	119.7(2)
		O(1)—C(15)—N(1)	125.3(2)
		O(1)—C(15)—C(2)	123.0(2)
		N(1)—C(15)—C(2)	111.7(2)
		C(17)—C(16)—S(1)	110.3(1)

30% H_2O_2 was added. The mixture was refluxed for 2 h and concentrated *in vacuo*. Water (10 mL) was added to the residue. The precipitate of **7a** (**7d**) was filtered off, washed with water (3×10 mL), dried in air, and recrystallized from an acetone—Pr^iOH mixture.

C. A weak stream of chlorine was passed through solutions of 2-[alkyl(aryl)sulfinyl]-4-nitrobenzamides **12a—d,g,h** (2 mmol) in glacial AcOH (3 mL) at 20 °C for 10 min (TLC control). The solvent and the excess of chlorine were removed *in vacuo*. Cold water (5 mL) was added to the residues. The precipitates of **7a—d,g,h** were filtered off, dried in air, and recrystallized from Pr^iOH.

Synthesis of 1-[alkyl(aryl)sulfonyl]anthraquinone-2-carbonitriles (8a—d) (general procedure). A weak stream of chlorine was passed with stirring through solutions of 1-[alkyl(aryl)thio]anthraquinone-2-carboxamides **5a—d** (0.96 mmol) in 50% aqueous CF_3COOH (6 mL) at 20 °C for 15 min (TLC control). The reaction mixtures were stirred for 4 h and poured into water (15 mL). The precipitates that formed were filtered off, washed with water (3×8 mL), dried in air, recrystallized from a 3 : 1 ethanol—THF mixture, and chromatographed on a column with silica gel (L 40/100; toluene and then a 2 : 1 toluene—ethyl acetate mixture as the eluent) to isolate products **8a—d**.

Chromatography of the oxidative dehydration product of 1-butylthioanthraquinone-2-carboxamide (**5c**) afforded 1-butyl-6,11-dihydro-3*H*-1λ^4-anthra[2,1-*d*]isothiazole-3,6,11-trione 1-oxide (**10**) (R_f = 0.35) along with 1-butylsulfonylanthraquinone-2-carbonitrile **8c** (R_f = 0.75).

Synthesis of 3-substituted 5-alkylsulfonylisothiazole-4-carbonitriles (9a—e). ***A.*** A weak stream of chlorine was passed with stirring through suspensions of amides **6a—e** (1.96 mmol) in 85% aqueous AcOH (6 mL) at 20 °C for 10 min (TLC control). Compounds **9a—e** were filtered off, washed with water (10 mL), dried in air, and recrystallized from THF.

B. *m*-Chloroperoxybenzoic acid (60% purity, 0.70 g, 2.43 mmol) was added to a solution of nitrile **15a** (0.15 g, 0.81 mmol) in CH_2Cl_2 (4 mL) and the mixture was stirred at 20 °C for 1 h. The solvent was distilled off under reduced pressure and the precipitate of **9a** was recrystallized from hexane.

C. A 50% H_2O_2 solution (0.60 mL, 11.4 mmol) was added to a solution of the nitrile **15b** (0.10 g, 0.52 mmol) in AcOH (2 mL). The reaction mixture was heated at 50 °C for 4 h. The course of the reaction was monitored by TLC. The solvent was distilled off under reduced pressure and the precipitate of **9b** was recrystallized from a THF—Pr^iOH mixture.

Synthesis of 2-[alkyl(aryl)sulfinyl]-4-nitrobenzamides (12a—d,g,h) (general procedure). A 30% H_2O_2 solution (0.5 mL, 4.85 mmol) was added to suspensions of the corresponding 2-alkyl(aryl)thio-4-nitrobenzamide **4a—d,g,h** (4 mmol) in glacial AcOH (5 mL) at 5—10 °C. The reaction mixtures were stirred until the starting compounds were consumed (TLC control) and poured into water (100 mL). The precipitates of compounds **12a—d,g,h** that formed were filtered off, washed with water (2×10 mL), dried in air, and recrystallized from acetone.

Synthesis of 2-[alkyl(aryl)thio]-4-nitrobenzonitriles (14a,d) (general procedure). Phosphorus oxychloride (3.1 mL, 33.83 mmol) was added dropwise to a stirred solution of amide **4a** or **4d** (25.84 mmol) in DMF (20 mL) at 5 °C. The reaction mixture was stirred at 20 °C for 2 h and poured onto ice (20 g). The precipitate of **14a** or 1**4d** was filtered off, washed with water (3×15 mL), dried in air, and recrystallized from an acetone—Pr^iOH mixture.

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