Synthesis of 1-phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-one (furanoanthrone) derivatives by the reaction of 1-acyloxy-9,10-anthraquinones with benzyl cyanide

I. Ya. Mainagashev and L. S. Klimenko*

Novosibirsk Institute of Organic Chemistry, Sibirian Branch of the Russian Academy of Sciences,
9 prosp. Acad. Lavrent'eva, 630090 Novosibirsk, Russian Federation.
Fax: 007 (383 2) 35 4752. E-mail: root@orchem.nsk.su

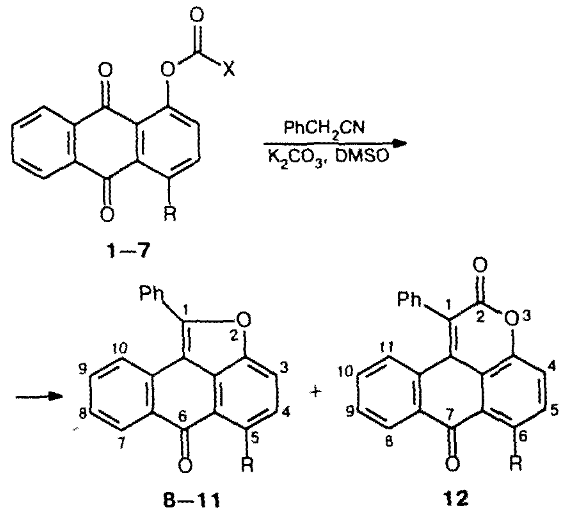
The reactions of various 1-acyloxyanthraquinones with benzyl cyanide in DMSO in the presence of K_2CO_3 were studied. 1-Phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-one derivatives are formed as the main reaction products. In the case of unsubstituted 1-acyloxyanthraquinones, 1-phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-one and 1-phenylanthra[1,9-*b*,*c*]pyran-2,7-dione were isolated. It was shown that furanoanthrones can be synthesized in two steps *via* the corresponding pyronoanthrones.

Key words: 1-phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-one, 1-phenylanthra[1,9-*b*,*c*]pyran-2,7-dione.

Previously[1] we studied the reactions of stable 9-phenoxy-1,10-anthraquinones with alcohols and amines. 1-Acyloxyanthraquinones are potential precursors of compounds with a 1,10-anthraquinoid structure. For example, it has been shown that the reaction of 1-acetoxyanthraquinones with amines under alkaline conditions may involve the intermediate formation of 9-acetoxy-1,10-anthraquinones.[2]

In the present work, to continue the investigation of the reactivity of 1,10-anthraquinones towards nucleophilic reagents, we studied the reaction of 1-acyloxyanthraquinones (**1**—**7**) bearing various substituents both in the acyl group and in the anthraquinone nucleus with benzyl cyanide (*i.e.*, with a C-nucleophile). It was found that, instead of the expected 1-hydroxy-9-phenylcyanomethylideneanthrones, the reactions yield 1-phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-ones (**8**—**11**, furanoanthrones, Scheme 1). This class of compound has not been studied; the synthesis of "benzoin yellow" dye involving construction of the furanoanthrone framework is the only example that has been reported.[3]

Scheme 1

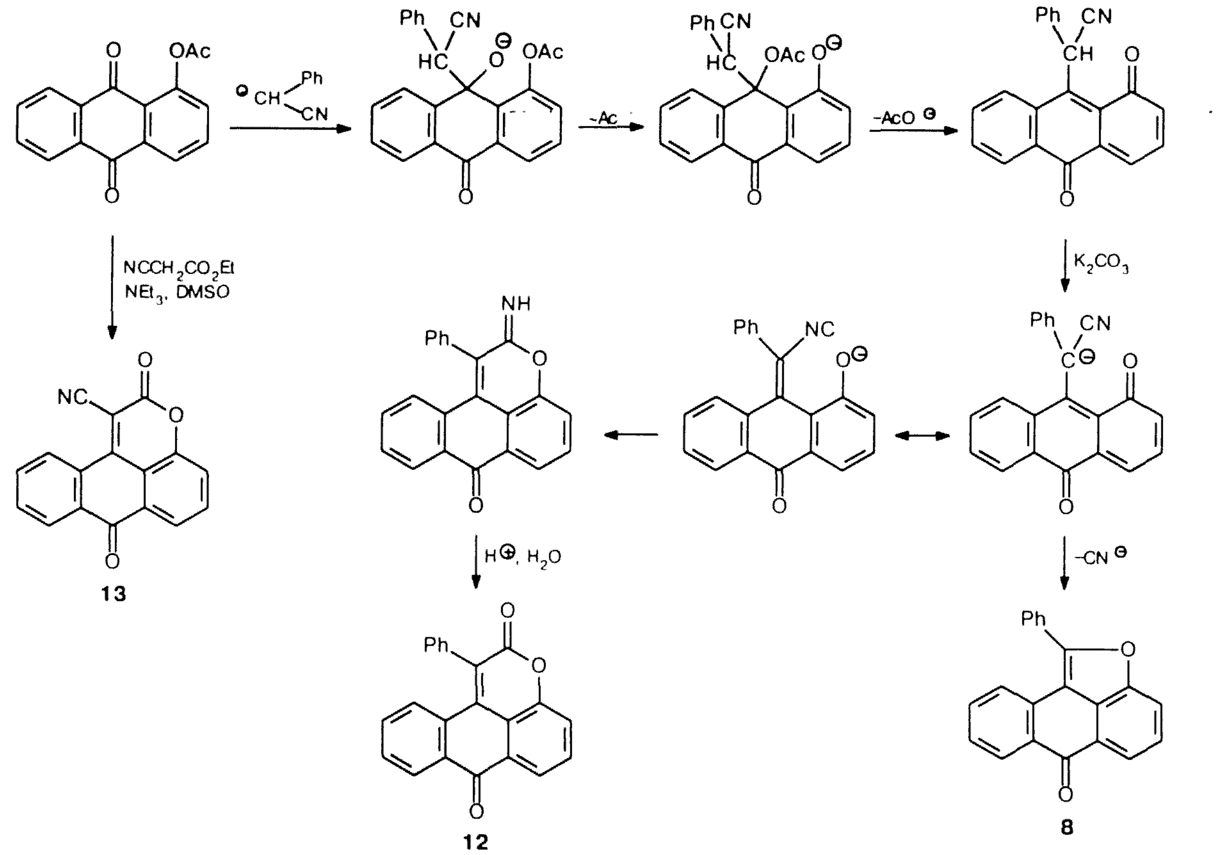


X = Me (**1**, **5**—**7**); $CHMe_2$ (**2**); NMe_2 (**3**); NPh_2 (**4**);
R = H (**1**—**4**, **8**, **12**); Cl (**5**, **9**); OMe (**6**, **10**); NHAc (**7**, **11**)

Initially, we studied the reactions of benzyl cyanide with unsubstituted 1-acetyl-, 1-*iso*-butyryl-, 1-*N*,*N*-dimethylcarbamoyl-, and 1-*N*,*N*-diphenylcarbamoyloxyanthraquinones (**1**—**4**). The processes were carried out in dry DMSO in the presence of freshly calcined K_2CO_3 at room temperature. The reaction duration was 30—60 min for compounds **1** and **2** and 3—5 h for compounds **3** and **4**. It was found that 1-phenylanthra[1,9-*b*,*c*]pyran-2,7-dione (**12**, 20—30 %) is formed along with 1-phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-one (**8**, 45—55 %) and that the ratio between these products virtually does not depend on the structure of the acyl moiety of the molecule. Elemental analysis showed that neither of these products contain nitrogen. Their molecular weights found from the mass spectra correspond to the molecular formulae of **8** and **12**. The signals for H(10) and H(11) in the ^1H NMR spectra of compounds **8** and **12** are shifted upfield with respect to the signal for H(8) in the starting 1-acetoxyanthraquinone (**1**), due to the absence of the neighboring carbonyl group. The magnitudes of this shift ($\Delta\delta$) are −0.1 ppm for com-

Translated from *Izvestiya Akademii Nauk. Seriya Khimicheskaya*, No. 11, pp. 2710—2714, November, 1996.

Scheme 2



pound **8** and −1.1 ppm for compound **12**. Furanoanthrone **8** is a light yellow compound exhibiting luminescence with a λ_{max} of 392 nm. The hypsochromic shift of λ_{max} with respect to that for the isomeric 2-phenyl-6*H*-anthra[9,1-*b*,*c*]furan-6-one (λ_{max} 586 nm)[4] is strong evidence for the 9,10-anthraquinoid structure of compound **8**. The IR spectrum of pyronoanthrone **12** exhibits a band corresponding to the exocyclic carbonyl group, in addition to the band due to the anthrone C=O group (Table 1). All these facts are in good agreement with the structures proposed for the reaction products. It should be noted that methods for the synthesis of iso-

Table 1. Yields, melting points, and physicochemical characteristics of compounds **8—13**

Compound	Yield (%)	M.p./°C (toluene—ethanol)	Found/Calculated (%)			Molecular formula	M⁺, *m/z* Found/Calculated	IR spectrum, ν/cm⁻¹ C=O	UV spectrum, λ_{max}/nm (log ε)
			C	H	Cl, N				
8	45—55	184—185	85.13 85.12	4.06 4.08		$C_{21}H_{12}O_2$	296.0831 296.0837	1660	300 (4.26), 392 (4.24)
9	89	240—242	76.22 76.25	3.43 3.35	10.70 10.72	$C_{21}H_{11}ClO_2$	330.0433 330.0448	1660	300 (4.22), 391 (4.20)
10	60	198—200	80.91 80.97	4.35 4.32		$C_{22}H_{14}O_3$	326.0932 326.0943	1645	302 (4.18), 386 (4.30)
11	40	229—231	78.56 78.17	4.28 4.28	3.85 3.96	$C_{23}H_{15}NO_3$	353.1057 353.1052	1690, 1630, 1620	306 (4.18), 408 (4.28)
12	20—30	253—255	81.95 81.47	3.80 3.73		$C_{22}H_{12}O_3$	324.0778 324.0786	1710, 1660	302 (4.07), 391 (4.03)
13	82	329—330	74.68 74.73	2.46 2.58	4.84 5.13	$C_{17}H_7NO_3$	273.0434 273.0426	2210 (C≡N), 1720, 1660	256 (4.15), 264 (4.21), 329 (4.23), 357 sh (4.09), 396 sh (3.85), 479 (<2.60)

meric 2-phenylfuranoanthrones are known, as are their reactions, their electronic structure, and their spectral and acid-base properties.[4,5]

The formation of products **8** and **12** from 1-acetoxyanthraquinone can be described by Scheme 2. The first step involves the addition of a carbanion to position 9 and the subsequent migration of the acetyl group. In the next step, an acetate anion is eliminated to give 9-phenylcyanomethyl-1,10-anthraquinone, which is then ionized by a base. This is followed either by intramolecular nucleophilic substitution to yield furanoanthrone **8** or by intramolecular addition at the CN group, which leads to pyronoanthrone **12**. It is noteworthy that evidence for the formation of the geminal adduct followed by the migration of the acetyl group has been obtained in relation to the anion of the *gem*-diol derived from 1-acetoxyanthraquinone.[2]

4-Substituted 1-acetoxyanthraquinones (**5**—**7**) were involved in the reaction with $PhCH_2CN$ in a similar way. The duration of the reaction of compound **7** was 15 min, and the reactions of compounds **5** and **6** proceeded for 1 h. The yields of the corresponding furanoanthrones **9**—**11** are listed in Table 1. In the case of chlorinated derivative **5**, the reaction occurs most smoothly and affords virtually no corresponding pyronoanthrone. In the case of methoxy derivative **6**, the pyronoanthrone is formed, and the reaction mixture undergoes some resinification. The reaction involving acetylamino derivative **7** proceeds similarly to the reaction of compound **6**; however, it affords some colored side products. We were not able to isolate the pyronoanthrones obtained from compounds **6** and **7** by chromatography, since they were eluted together with the resinoid reaction products. Due to resinification and also to the formation of pyronoanthrones and other nonisolable side products, the yields of furanoanthrones **10** and **11** are lower than that of compound **9**. All the furanoanthrones obtained are crystalline high-melting substances, whose color varies from light yellow (R = H, Cl) to yellow (R = OMe) or orange (R = NHAc). Solutions of compounds **8**—**11** in benzene and $CHCl_3$ exhibit luminescent properties under the action of UV irradiation.

In order to determine the ratio between products **8** and **12** as a function of the nature of the base used, we studied the reactions of 1-acetoxyanthraquinone with $PhCH_2CN$ in DMSO in the presence of a stronger (NaH) or a weaker (NEt_3) base. The reaction with NaH is accompanied by significant resinification, although the presence of compounds **8** and **12** in the reaction products is confirmed by TLC data. This fact hampers substantially investigation of the reaction. Conversely, the reaction involving NEt_3 proceeds smoothly in a homogeneous solution; however, it takes a long time. This reaction gives pyronoanthrone **12** in nearly quantitative yield. A similar reaction with ethyl cyanoacetate affords 1-cyanoanthra[1,9-*b*,*c*]-pyran-2,7-dione (**13**) in a high yield (Scheme 2). The reactions with malononitrile and ethyl phenylacetate carried out in the presence of NEt_3 could be observed qualitatively by TLC; these reactions gave compounds **8**, **12**, and **13**.

The fact that this process is directed at pyronoanthrones **12** and **13** is due to the relatively low basicity of NEt_3. Apparently, this base is not strong enough to ionize the intermediate 9-phenylcyanomethyl-1,10-anthraquinone; however, the 1,3-sigmatropic shift of a hydrogen atom to the nitrogen atom of the cyano-group followed by closure of the pyran ring is possible (Scheme 3).

The ease of the formation of a pyran ring has been shown previously[6] in relation to 2,4-dichloro-1-hydroxy-9,10-anthraquinone-9-dicyanomethide.

In order to find whether pyronoanthrone **12** can be converted into furanoanthrone **8** under the reaction conditions, we carried out the reaction analytically pure compound **12** with K_2CO_3 in DMSO. Furanoanthrone **8**

Scheme 3

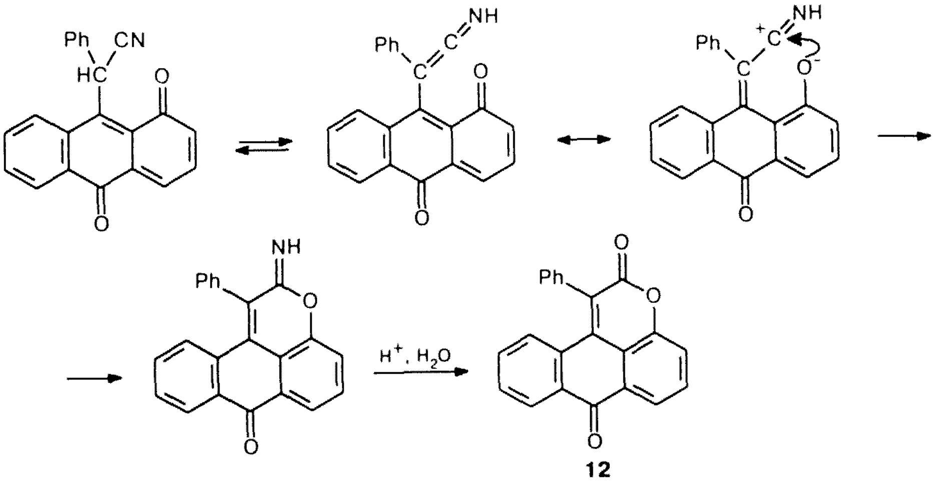


Table 2. Chemical shifts (δ) and spin coupling constants (*J*/Hz) in the ^{1}H NMR spectra of compounds **8—11**

Compound	C_6H_5 (m)	H(3) (d)	H(4)	H(5) (d), R	H(7) (m)	H(8), H(9) (m)	H(10) (m)
8	7.48—7.60	7.74 (*J* = 7.5)	7.57 (t, *J* = 7.5)	8.14 (*J* = 7.5)	8.54	7.95	8.13
9	7.48—7.63	7.52 (*J* = 8.5)	7.61 (d, *J* = 8.5)		8.50	7.91	8.05
10	7.44—7.61	7.68 (*J* = 8.5)	7.04 (d, *J* = 8.5)	4.09 (s, OCH_3)	8.56	7.91	8.09
11	7.44—7.63	7.67 (*J* = 9.0)	8.77 (d, *J* = 9.0)	2.31 (s, Ac), 11.75 (s, N—H)	8.54	7.95	8.13

was actually isolated in a low yield. Probably, interaction with air moisture affords a hydroxide ion, which adds to the carbonyl group in compound **12**, and this is accompanied by opening of the pyrone ring. This is followed by intramolecular nucleophilic substitution and by the abstraction of, apparently, a formate or carbonate anion, which leads to furanoanthrone **8**. According to TLC data, the interaction of compound **12** with KOH in DMSO also affords compound **8**. However, complete transformation of compound **12** into **8** in the presence of KOH was accomplished in benzene under conditions of phase transfer catalysis; this can be proposed as one more preparative method for the synthesis of furanoanthrones.

Thus, in the present work it was shown that 1-phenylfuranoanthrones can be easily prepared by the reaction of 1-acyloxyanthraquinones with $PhCH_2CN$ in DMSO in the presence of K_2CO_3 and also that furanoanthrones can be synthesized in two steps *via* the corresponding pyronoanthrones.

Experimental

IR spectra were recorded on a UR-20 spectrophotometer for pellets with KBr, and the electronic absorption spectra were obtained on a Specord UV-VIS spectrophotometer in ethanol (at a concentration of $1 \cdot 10^{-4}$ mol L^{-1}). The ^{1}H NMR spectra were recorded in $CDCl_3$ on a Bruker WP-200SY instrument (chemical shifts are given in the δ scale; tetramethylsilane was used as the internal standard). The EI mass spectra were obtained on a Finnigan MAT-8200 mass spectrometer; the *m/z* values for the molecular ion (M^+) are given. Chromatography was carried out on columns packed with silica gel L (100—250 mm). The preparative TLC was conducted on plates with silica gel L (0—140 mm), and TLC was carried out on Silufol UV-254 plates.

The yields, melting points, and physicochemical properties of the compounds synthesized are presented in Table 1, and their ^{1}H NMR spectra are given in Table 2.

1-Acyloxyanthraquinones **1—4** were prepared by the acylation of the corresponding 1-hydroxyanthraquinones with acyl chlorides in pyridine by a procedure similar to that described previously.[7]

1-Phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-one (8) and **1-phenylanthra[1,9-*b*,*c*]pyran-2,7-dione (12).** $PhCH_2CN$ (1.5—2.25 mmol) and a fivefold excess of K_2CO_3 were added to solutions of compounds **1—4** (1.0—1.5 mmol) in DMSO. The mixture was stirred at ~20 °C until the starting compound disappeared (TLC monitoring). The reaction mixture was poured into water and neutralized with AcOH. The precipitate was filtered off, washed with water, and dried. Then it was chromatographed on a column with SiO_2 (using benzene as the eluent). From the first yellow zone, which luminesced under UV radiation, compound **8** was isolated. From the second yellow zone, pyronoanthrone **12** was obtained (elution with $CHCl_3$). ^{1}H NMR ($CDCl_3$), δ: 7.12—7.26 (m, 3 H, H(9), H(10), H(11)); 7.37—7.55 (m, 5 H, C_6H_5); 7.64 (d, 1 H, H(4), *J* = 7 Hz); 7.74 (t, 1 H, H(5), *J* = 7 Hz); 8.27 (d, 1 H, H(6), *J* = 7 Hz); 8.39 (д, 1 H, H(8), *J* = 7 Hz).

1-Phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-ones (9—11) were prepared similarly to compound **8** by the reaction of the corresponding 4-substituted 1-acetoxyanthraquinones **5—7** with benzyl cyanide.

1-Cyanoanthra[1,9-*b*,*c*]pyran-2,7-dione (13). $PhCH_2CN$ (0.3 g, 2.65 mmol) and 1 mL of NEt_3 were added to a solution of compound **1** (0.54 g, 2.03 mmol) in DMSO. The reaction mixture was kept for 18 h at ~20 °C, poured into water, and neutralized with AcOH. The precipitate was filtered off. The dried product was purified by column chromatography (using $CHCl_3$ as the eluent); the yellow zone containing product **13** was collected. ^{1}H NMR ($CDCl_3$), δ: 7.17 (t, 1 H, H(5), *J* = 7.5 Hz); 7.69 (d, 1 H, H(4), *J* = 7.5 Hz); 7.89 (m, 2 H, H(9), H(10)); 8.34 (d, 1 H, H(6), *J* = 7.5 Hz); 8.55 (m, 1 H, H(11)); 9.37 (m, 1 H, H(8)).

1-Phenylanthra[1,9-*b*,*c*]pyran-2,7-dione (12) was obtained by the reaction of compound **1** with $PhCH_2CN$ in DMSO in the presence of NEt_3, similarly to compound **13**. Yield 89%.

1-Phenyl-6*H*-anthra[1,9-*b*,*c*]furan-6-one (8). A. A fivefold excess of K_2CO_3 was added to a solution of pyronoanthrone **12** (0.2 g, 0.62 mmol) in DMSO. The mixture was heated for 1 h at 100 °C, cooled, and poured into water. Then the mixture was neutralized by AcOH, and the precipitate was filtered off. The dried mixture was separated by column chromatography (using benzene as the eluent). The yellow fraction containing compound **8** was isolated. Yield 0.046 g (25%).

B. Finely powdered KOH (0.3 g, 5.4 mmol) and Bu_4NBr (0.1 g, 0.31 mmol) were added to a suspension of pyronoanthrone **12** (0.2 g, 0.62 mmol) in benzene (50 mL). The mixture was boiled with stirring for 2 h until the starting compound disappeared. After cooling, the reaction mixture was separated by column chromatography on silica gel using benzene as the eluent to give 0.15 g (82%) of compound **8**.

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Received March 20, 1996;
in revised form June 10, 1996