Cyclization of 1-hydroxy-2-(oxoalkynyl)anthraquinones

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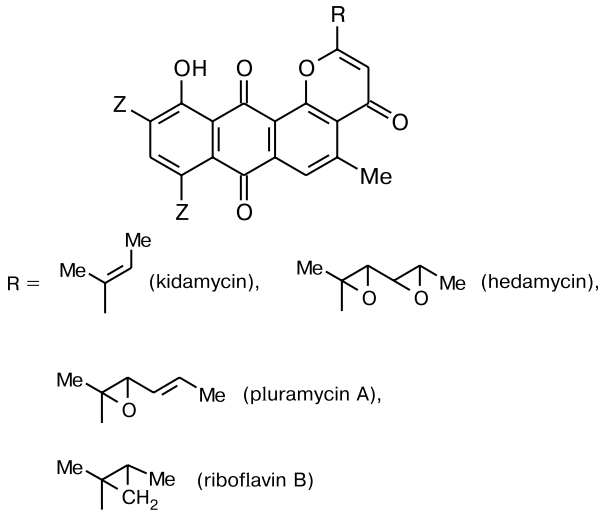
Procedures were developed for the heterocyclization of 2-benzoylethynyl-1-hydroxy- and 1-hydroxy-2-(1-oxo-3-phenylpropynyl)anthraquinone. The regioselective preparation of 2-substituted anthra[1,2-*b*]pyran-4,7,12-triones was demonstrated to be possible under mild conditions.

Key words: anthraquinones, anthra[1,2-*b*]pyrantriones, anthra[1,2-*b*]furandiones, heterocyclization, alkynones, enamines, iodination.

The anthra[1,2-*b*]pyran-4,7,12-trione fragment is present as a cyclic moiety in antitumor antibiotics of the kidamycin group and a series of their biologically active analogs prepared by biochemical methods.[1,2] In spite of a considerable amount of data on the biological properties of anthrapyran compounds, procedures for their synthesis have not been sufficiently developed. It should be noted that general procedures for the construction of the benzopyrone structure are known[3] and can be used for the synthesis of anthra[1,2-*b*]pyrantriones.[4,5] It is much more difficult to introduce an unsaturated or another chemically labile substituent, which is analogous to those present in kidamycin antibiotics, at position 2 of these compounds.



Z are amino sugar residues

One of the possible approaches to construct the 2-alkenylanthrapyran structure was used for the first time in the synthesis of kidamycinone methyl ether (aglycone methyl ether of kidamycin).[1,6] The key step of this process is the formation of the alkenylpyrone ring involving the adjacent hydroxy and 4-methyl-2,4-hexadienoyl groups. The corresponding 9,10-dimethoxyanthracene derivative was cyclized by prolonged heating with SeO_2 in *tert*-amyl alcohol to prepare the dehydrocyclization product in a yield of ~30%. More recently, an alternative synthesis of 2-alkenylanthra[1,2-*b*]pyran-4,7,12-triones starting from acetylenic derivatives of anthraquinone has been briefly described.[7]

In the present study, we examined various procedures for the synthesis of 2-substituted anthrapyrantriones within the framework of the acetylenic approach. The aim was to search for regioselective and mild methods of cyclization of acetylenic precursors, which can be used for the synthesis of the target anthrapyrantriones containing chemically labile substituents.

This strategy of the formation of the pyran ring angularly fused to the anthraquinone moiety should involve the O atom of the hydroxy group, two C atoms of anthraquinone, and three C atoms of the acetylenic substituent. Evidently, it is advantageous to use the 3- or 1-oxopropynyl group as an active three-carbon fragment. Actually, these groups are chemically equivalent to the β-diketone group, which is prone to interact with the *ortho*-arranged hydroxy function resulting in the six-membered ring closure.[3] Therefore, 1-hydroxy-2-(3-oxo-1-alkynyl)- or 1-hydroxy-2-(1-oxo-2-alkynyl)anthraquinones can serve as acetylenic precursors of 2-substituted anthra[1,2-*b*]pyran-4,7,12-triones (Scheme 1).

To compare different methods of cyclization, we used accessible 2-benzoylethynyl-1-hydroxyanthraquinone (**1**) as a model key acetylenic compound.

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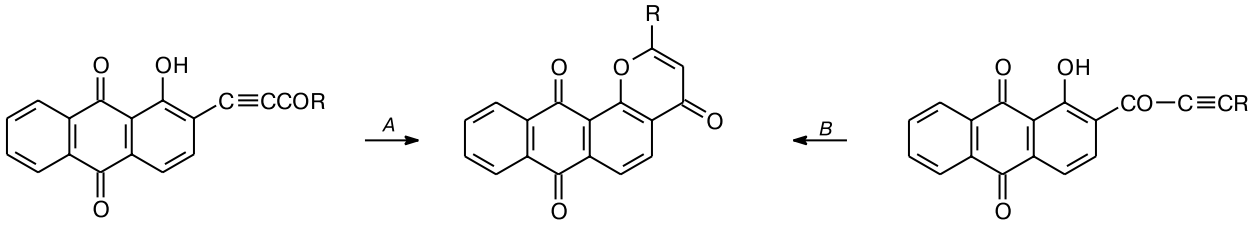
Scheme 1



Ketone **1** was prepared by condensation of 1-benzoyloxy-2-iodoanthraquinone (**2**) with cuprous benzoylacetylide (Scheme 2). The necessity of protecting the hydroxy group stems from the fact that *ortho*-hydroxyacetylenic aromatic compounds very readily undergo intramolecular cyclization in the presence of Cu^{I} salts to give benzofurans.[8]

1-Hydroxyanthraquinone (**3**) was iodinated with a mixture of I_2 and HIO_3 in boiling aqueous dioxane to give 1-hydroxy-2-iodoanthraquinone (**4**) in 87% yield. The benzoyl protection was introduced by refluxing hydroxy iodide **4** with benzoyl chloride in the presence of K_2CO_3 in acetone, the yield of benzoyl derivative **2** being 96%. Condensation of iodide **2** with cuprous benzoylacetylide in refluxing DMF was completed in 1.5 h to give acetylenic ketone **5** in 70% yield. The hydroxy group was almost quantitatively deprotected by stirring compound **5** in concentrated H_2SO_4 for 5 min.

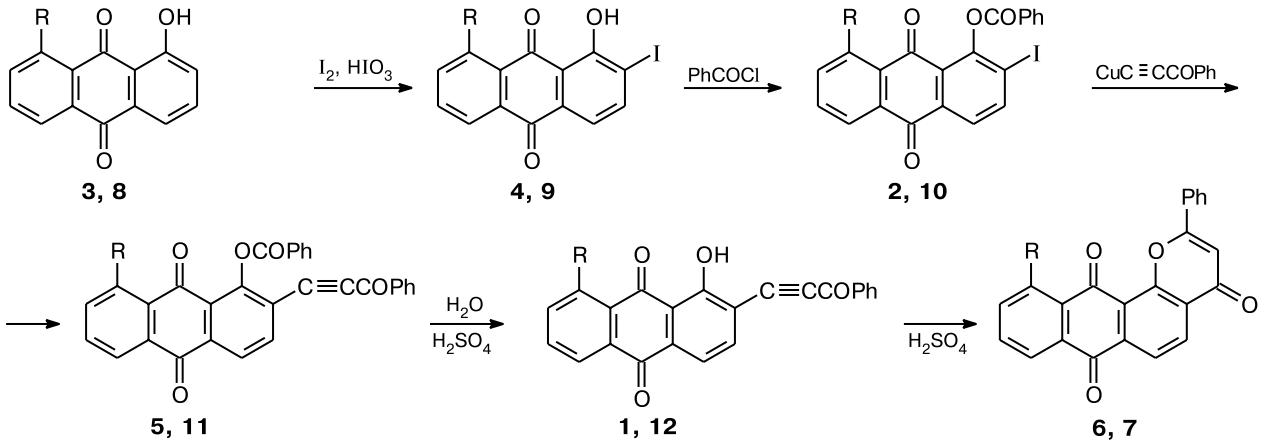
The simplest way of transforming model ketone **1** into 2-phenylanthra[1,2-*b*]pyran-4,7,12-trione (**6**) is based on its cyclization under conditions of hydration at the triple bond. The cyclization occurs easily on brief heating in concentrated H_2SO_4 (70 °C, 30 min). Evidently, the removal of the benzoyl protection can be combined with the cyclization step. The yield of compound **6** derived from benzoyloxy derivative **5** without isolation of hydroxy ketone **1** was 86%.

One of the goals in the development of approaches to the synthesis of biologically active anthrapyrantriones is to introduce and retain substituents (in the simplest case, the hydroxy group) in the terminal benzene ring of the fused system in the course of construction of the pyran ring (it is highly probable that the presence of the hydrophilic hydroxy group affects substantially the biological activity of the compound[9]). In this connection, we attempted to extend the method used for the synthesis of pyrone **6** to its hydroxylated analog, *viz.*, 11-hydroxy-2-phenylanthra[1,2-*b*]pyran-4,7,12-trione (**7**).

Regioselective iodination of 1,8-dihydroxyanthraquinone (**13**) was carried out using successively the boron acetate and acetyl protections of the hydroxy groups[10] (Scheme 3).

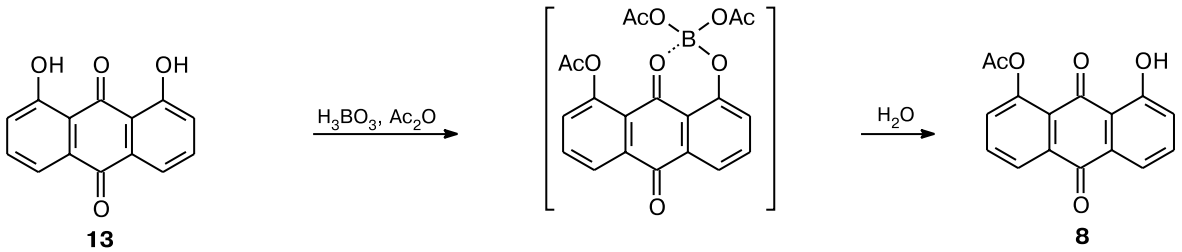
1-Acetoxy-8-hydroxyanthraquinone (**8**), which was prepared in 94% yield, was iodinated with an I_2—HIO_3 mixture in refluxing aqueous dioxane (see Scheme 2). The acetoxy group remained virtually intact in the course of the reaction, and the yield of 8-acetoxy-1-hydroxy-2-iodoanthraquinone (**9**) was 54%. Then 11-hydroxy-2-phenylanthra[1,2-*b*]pyran-4,7,12-trione (**7**) was synthesized analogously to pyran **6** using simultaneous

Scheme 2



R = H (**1—6**), OAc (**8—11**), OH (**7, 12**)

Scheme 3



deacylation of both hydroxy groups in compound **11** (concentrated H_2SO_4, 20 °C, 15 min).

Unfortunately, this method for the construction of the γ-pyrone ring is unsuitable for the preparation of compounds, which, like kidamycin antibiotics, contain acid-sensitive groups. Under alternative conditions, the starting acetylenic ketones containing the triple bond at the α,β position of the substituent, are more prone to cyclization with the closure of the five-membered heterocycle rather than with the six-membered ring closure. For example, model ketone **1** readily undergoes cyclization in the presence of cuprous phenylacetylide already at 20 °C to give 2-benzoylanthra[1,2-*b*]furan-6,11-dione (**14**) isomeric to pyrone **6**. As mentioned above, cyclocondensation of unprotected hydroxy iodide **4** with cuprous benzoylacetylide afforded the same furan **14** (Scheme 4). In alkaline media, cyclization is additionally complicated by the cleavage of the keto acetylenic group.[11]

The ^{1}H NMR spectrum of anthrafurandione **14** shows a signal for the proton of the benzoyl-substituted aromatic five-membered heterocycle at substantially lower field than the signal for the proton of the phenyl-substituted pyrone ring observed in the spectrum of isomeric anthrapyrantrione **6** (Δδ ~0.7). In addition, the signals for the protons of the benzene ring annelated with the heterocycle are observed in the spectrum of compound **6** at lower field than those in the spectrum of compound **14** (δ 8.66 and 8.39 compared to δ 8.34 and 8.13). A comparison of the spectra of compounds **6**, **14**, and **7** and ketones **1**, **5**, **11**, **12**, and **15** (Tables 1 and 2) suggests that the signals at δ 8.66 (pyran **6**) and 8.13 (furan **14**) belong to the proton adjacent to the bridgehead position of the fused benzene—heterocycle system and, consequently, the chemical shift of this proton is most substantially affected by the structure of the heterocycle. The chemical shifts of other protons of the benzene ring in molecule **6** are virtually identical to those of **14**. Evidently, these characteristic features of the ^{1}H NMR spectra of quinones **6** and **14** can be used to establish the structures of related compounds.

We expected that the transfer of the carbonyl group from the γ to α position of the substituent in key precursor **1** would facilitate the formation of the pyrone ring and allow us to perform cyclization under rather mild conditions (see Scheme 1, path *B*). To test this assumption, model ketone **1** was isomerized to 1-hydroxy-2-(1-oxo-3-phenylpropynyl)anthraquinone (**15**) (Scheme 5) by the successive addition of amine, the preparation of iminium salt **16** by the reaction of $POCl_3$ with adduct **17**, and its alkaline hydrolysis.[12]

An excess of piperidine was added to ketone **1** (20 °C, 15 min) to prepare aminovinyl ketone **17** in 89% yield. Heating of adduct **17** with $POCl_3$ in dioxane afforded iminium salt **16**, which was decomposed (without isolation) with 10% aqueous KOH. The yield of ketone **15** was 40%. It appeared that ketone **15** underwent partial cyclization to benzylideneanthra[1,2-*b*]furan-3,6,11-trione (**18**) in the course of the synthesis. This secondary reaction occurs, apparently, in an alkaline medium in the course of decomposition of iminium salt **16**. Ketone **15** was completely transformed into furanone **18** on heating in the presence of cuprous phenylacetylide in toluene. Consequently, the transfer of the carbonyl group in acetylenic ketone does not exclude the possibility of the formation of the five-membered ring. Apparently, the tendency to the five-membered ring closure is retained due, in part,

Scheme 4

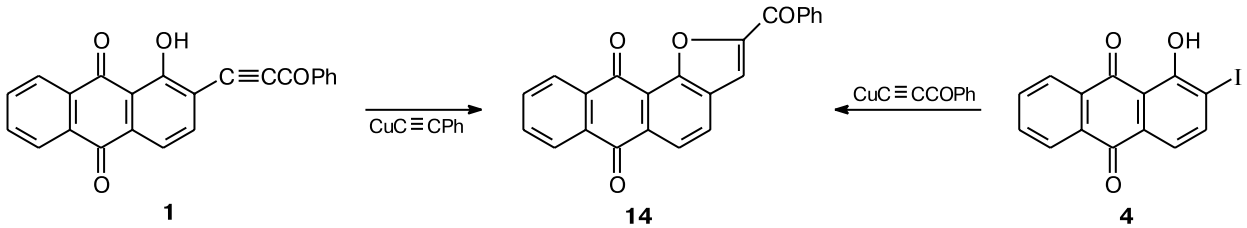


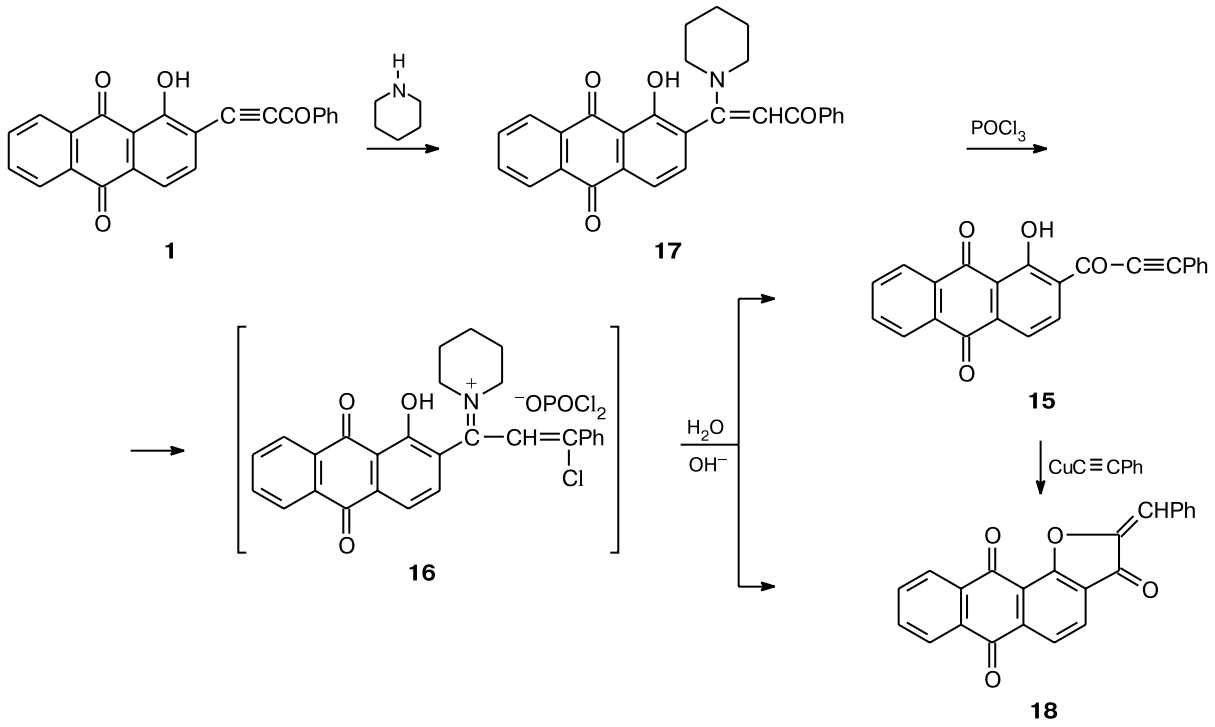
Table 1. Physicochemical properties of acetylenic ketones derived from anthraquinone

Compound	M.p./°C (benzene—hexane)	Found / Calculated (%) C	Found / Calculated (%) H	Molecular formula	^{1}H NMR ($CDCl_3$, δ, *J*/Hz)	IR, ν/cm^{-1}
1	209—211	78.53 78.40	3.48 3.43	$C_{23}H_{12}O_4$	7.45—7.70 (m, 3 H, 3 HPh$_{m,p}$); 7.80—7.90 (m, 3 H, H(4) (H(3)), H(6), H(7)); 8.00 (d, 1 H, H(3) (H(4)), *J* = 7.9); 8.25—8.40 (m, 4 H, 2 HPh$_o$, H(5), H(8)); 13.30 (s, 1 H, OH)	1645, 1680 (C=O); 2215 (C≡C)
5	230—231.5	78.73 78.94	3.48 3.58	$C_{30}H_{16}O_5$	7.00—7.15 (m, 2 H, 2 HPh$_m$, ≡CCOPh); 7.35—7.50 (m, 1 H, 1 HPh$_p$, =CCOPh); 7.50—7.65 (m, 1 H, 2 HPh$_m$, OCOPh); 7.65—7.85 (m, 3 H, H(6), H(7), 1 HPh$_p$, OCOPh); 7.90—8.00 (m, 2 H, 2 HPh$_o$, ≡CCOPh); 8.10—8.25 (m, 1 H, H(5) (H(8))); 8.17 (d, 1 H, H(3) (H(4)), *J* = 8.1); 8.25—8.30 (m, 1 H, H(8) (H(5))); 8.30—8.45 (m, 2 H, 2 HPh$_o$, OCOPh); 8.39 (d, 1 H, H(4) (H(3)), *J* = 8.0)	1645, 1680 (C=O); 1750 (O—C=O); 2220 (C≡C)
11	212—214	74.74 74.70	3.40 3.53	$C_{31}H_{18}O_7$	2.05 (s, 3 H, Me); 7.05—7.15 (m, 2 H, 2 HPh$_m$, ≡CCOPh); 7.40 (dd, 1 H, H(7), *J* = 8.1, *J* = 1.3); 7.40—7.50 (m, 1 H, 1 HPh$_p$, ≡CCOPh); 7.55—7.65 (m, 2 H, 2 HPh$_m$, OCOPh); 7.65—7.75 (m, 1 H, 1 HPh$_p$, OCOPh); 7.79 (t, 1 H, H(6), *J* = 7.9); 7.95—8.05 (m, 2 H, 2 HPh$_o$, ≡CCOPh); 8.12 (d, 1 H, H(3) (H(4)), *J* = 8.1); 8.23 (dd, 1 H, H(5), *J* = 7.8, *J* = 1.3); 8.30—8.40 (m, 2 H, 2 HPh$_o$, OCOPh); 8.30 (d, 1 H, H(4) (H(3)), *J* = 8.1)	1650, 1685 (C=O); 1765 (O—C=O); 2220 (C≡C)
12	218—220	75.17 75.00	3.18 3.28	$C_{23}H_{12}O_5$	7.34 (d, 1 H, H(7), *J* = 7.9); 7.50—7.65 (m, 3 H, 3 HPh); 7.74 (t, 1 H, H(6), *J* = 7.9); 7.87 (d, 2 H, H(4) (H(3)), H(5), *J* = 7.9); 8.01 (d, 1 H, H(3) (H(4)), *J* = 7.9); 8.25—8.35 (m, 2 H, 2 HPh); 11.92 (s, 1 H, OH); 12.80 (s, 1 H, OH)	1640, 1680 (C=O); 2215 (C≡C)
15	185—186[5]	—	—	$C_{23}H_{12}O_4$	7.35—7.50 (m, 3 H, 3 HPh); 7.65—7.75 (m, 2 H, 2 HPh); 7.80—7.90 (m, 2 H, H(6), H(7)); 8.25—8.40 (m, 2 H, H(5), H(8)); 7.91 (d, 1 H, H(4) (H(3)), *J* = 8.1); 8.46 (d, 1 H, H(3) (H(4)), *J* = 8.1); 13.76 (s, 1 H, OH)	1650, 1685 (C=O); 2190 (C≡C)

Table 2. Physicochemical properties of fused heterocyclic anthraquinone derivatives

Compound	M.p./°C (benzene—hexane)	Found / Calculated (%) C	Found / Calculated (%) H	Molecular formula	^{1}H NMR ($CDCl_3$, δ, *J*/Hz)
6	326—327[5] (dichloroethane)	—	—	$C_{23}H_{12}O_4$	7.01 (s, 1 H, H(3)); 7.60—7.70 (m, 3 H, 3 HPh); 7.80—7.90 (m, 2 H, H(9), H(10)); 8.25—8.40 (m, 4 H, 2 HPh, H(8), H(11)); 8.39 (d, 1 H, H(6) (H(5)), *J* = 8.2); 8.66 (d, 1 H, H(5) (H(6)), *J* = 8.2)
7	342—344	74.79 75.00	3.27 3.28	$C_{23}H_{12}O_5$	7.01 (s, 1 H, H(3)); 7.39 (d, 1 H, H(10), *J* ≈ 8.2); 7.55—7.65 (m, 3 H, 3 HPh); 7.71 (t, 1 H, H(9), *J* = 8.0); 7.85 (d, 1 H, H(8), *J* ≈ 8.0); 8.25—8.35 (m, 2 H, 2 HPh); 8.37 (d, 1 H, H(6) (H(5)), *J* = 8.2); 8.69 (d, 1 H, H(5) (H(6)), *J* = 8.2); 12.82 (s, 1 H, OH)
14	268—270 (dichloroethane)	78.45 78.40	3.51 3.43	$C_{23}H_{12}O_4$	7.74 (s, 1 H, H(3)); 7.60—7.70 (m, 3 H, 3 HPh); 7.75—7.85 (m, 2 H, H(8), H(9)); 8.13 (d, 1 H, H(4) (H(5)), *J* = 8.3); 8.34 (d, 1 H, H(5) (H(4)), *J* = 8.3); 8.30—8.50 (m, 4 H, 2 HPh, H(7), H(10))
18	298—300	78.37 78.40	3.41 3.43	$C_{23}H_{12}O_4$	7.07 (s, 1 H, =CH); 7.45—7.65 (m, 3 H, 3 HPh); 7.80—7.90 (m, 2 H, H(8), H(9)); 8.15—8.40 (m, 6 H, H(4), H(5), H(7), H(10), 2 HPh)

Scheme 5

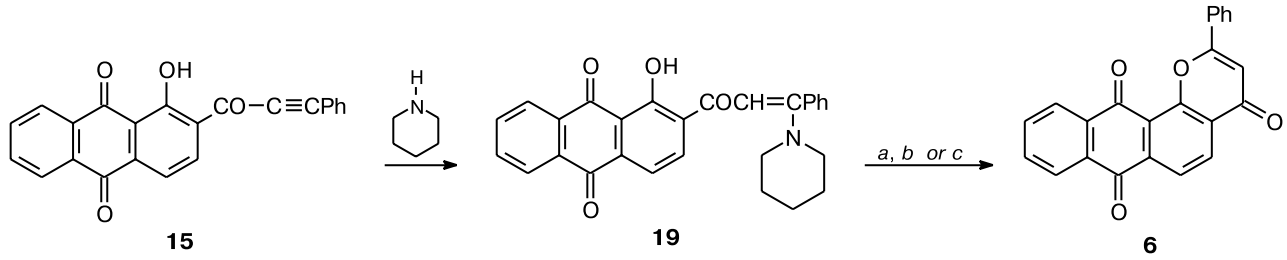


to the fact that the strongest electrophilic center of the adjacent substituent, *viz.*, the acetylenic C atom at the β position with respect to the carbonyl group, is spatially remote from the O atom of the hydroxy group. Evidently, the formation of the six-membered ring requires that this C atom and the O atom of the hydroxy group be in spatial proximity. This can readily be achieved by the addition of secondary amine at the triple bond of compound **15** (Scheme 6).

Actually, adduct **19** gave pyrone **6** upon heating in a $CHCl_3$—dioxane—water mixture acidified with a small amount of H_2SO_4 (method *a*), *i.e.*, under substantially milder conditions than those used for cyclization of 2-benzoylethynyl-1-hydroxyanthraquinone (**1**). Nevertheless, the possibility of using this procedure for the synthesis of anthrapyrantriones containing acid-sensitive substituents is in doubt. Base-catalyzed cyclization of the adduct leading to the intramolecular nucleophilic substitution of the dialkylamino group holds more promise.[13] Another advantage of this procedure is that it allows one to combine the steps of adduct formation and cyclization. The reaction of acetylenic ketone **15** was carried out with the use of more than one equivalent of piperidine in anhydrous benzene (method *b*). At 80 °C, the reaction time was 1 h; the yield of pyran **6** was 83% (the method *a* produced pyran **6** in 51% yield).

During monitoring of the adduct formation and cyclization by TLC, we paid attention to instability of aminovinyl ketone **19** on silica gel and found that it was transformed into anthrapyran **6** already on the adsorbent.

Scheme 6



Reagents and conditions: *a*. H_2SO_4 (cat.)/$CHCl_3$—dioxane—H_2O; *b*. Piperidine, C_6H_6, 80 °C; *c*. Silica gel, 20 °C.

This provided the basis for developing yet another mild and convenient method of cyclization of adduct **19** (method *c*). Cyclization occurs once a chloroform solution of adduct **19** is deposited on the adsorbent, the color of the adsorbed compound being changed from red to yellow. The reaction was completed in 2 h; the yield of anthrapyrantrione **6** was 82%.

Therefore, under particular reaction conditions, model ketone **1** and its isomer **15** undergo regioselective cyclization to form the 2-substituted γ-pyrone ring. It is advantageous to perform the synthesis of anthrapyranoquinones containing chemically labile substituents at position 2 starting from 2-(1-oxoalkyn-2-yl)anthraquinones **15**, which can undergo cyclization, through piperidine adducts **19** under mild conditions (methods *a*—*c*, see Scheme 6). The efficiency of this approach was supported by the successful synthesis of 2-alkenylanthra[1,2-*b*]pyran-4,7,12-triones.[7]

Experimental

The ^{1}H NMR spectra were recorded on a Bruker DPX-200 instrument (200 MHz) in $CDCl_3$ at 25 °C. The IR spectra were measured on a UR-20 spectrometer in $CHCl_3$. The course of the reactions and purity of the reaction products were monitored by TLC on Silufol UV 254 plates.

1-Acetoxy-8-hydroxyanthraquinone (8) was prepared according to a known procedure[10] by heating 1,8-dihydroxyanthraquinone (**13**) (4.80 g, 20 mmol) in Ac_2O (100 mL) in the presence of H_3BO_3 (5.00 g, 80 mmol) at 95 °C for 5 h. The yield of compound **8** was 5.30 g (94%), m.p. 191—192 °C (benzene—hexane).

1-Hydroxy-2-iodoanthraquinone (4). Iodine (1.12 g, 4.4 mmol) and HIO_3 (1.76 g, 10 mmol) in water (20 mL) were added to a solution of anthraquinone **3** (2.24 g, 10 mmol) in dioxane (60 mL) at 80 °C. The reaction mixture was refluxed with stirring for 2.5 h, cooled, and poured into water (300 mL). The precipitate that formed was filtered off, washed with water, and dried in air. After recrystallization from dioxane, compound **4** was obtained in a yield of 3.05 g (87%), m.p. 186—187 °C (benzene—hexane).[14]

8-Acetoxy-1-hydroxy-2-iodoanthraquinone (9) was synthesized analogously to iodoanthraquinone **4** from 1-acetoxy-8-hydroxyanthraquinone (**8**) (the reaction time was 6 h). The yield was 54%, m.p. 222—224 °C. Found (%): C, 47.26; H, 2.29; I, 31.18. $C_{16}H_9IO_5$. Calculated (%): C, 47.08; H, 2.22; I, 31.09. ^{1}H NMR, δ: 2.44 (s, 3 H, Me); 7.44 (dd, 1 H, H(7), J = 8.1 Hz, J = 1.3 Hz); 7.55 (d, 1 H, H(3), J = 8.1 Hz); 7.83 (t, 1 H, H(6), J = 8.0 Hz); 8.19 (d, 1 H, H(4), J = 8.1 Hz); 8.30 (dd, 1 H, H(5), J = 7.8 Hz, J = 1.3 Hz); 13.48 (s, 1 H, OH).

1-Benzoyloxy-2-iodoanthraquinone (2). A mixture of 1-hydroxy-2-iodoanthraquinone (**4**) (6.00 g, 17 mmol), benzoyl chloride (4.80 g, 34 mmol), and a K_2CO_3 powder (30.00 g, 220 mmol) in dry acetone (420 mL) was refluxed for 25 min and then filtered. Water (500 mL) was added to the filtrate. The precipitate that formed was separated, washed with water, and dried. The yield of benzoyl derivative **2** was 7.50 g (97%), m.p. 206—207 °C. Found (%): C, 55.65; H, 2.40; I, 28.00. $C_{21}H_{11}IO_4$. Calculated (%): C, 55.53; H, 2.44; I, 27.94. ^{1}H NMR, δ: 7.55—7.65 (m, 2 H, 2 HPh); 7.65—7.80 (m, 3 H, H(6), H(7), 1 HPh); 8.05 (d, 1 H, H(3), J = 8.3 Hz); 8.10—8.20 (m, 1 H, H(5) (H(8))); 8.20—8.30 (m, 1 H, H(8) (H(5))); 8.33 (d, 1 H, H(4), J = 8.3 Hz); 8.25—8.35 (m, 2 H, 2 HPh).

8-Acetoxy-1-benzoyloxy-2-iodoanthraquinone (10) was prepared analogously to compound **2** from 8-acetoxy-1-hydroxy-2-iodoanthraquinone (**9**). After recrystallization from a 1 : 1 benzene—hexane mixture, the yield of compound **10** was 79%, m.p. 204—206 °C. Found (%): C, 54.12; H, 2.51; I, 24.75. $C_{23}H_{13}IO_6$. Calculated (%): C, 53.93; H, 2.56; I, 24.77. ^{1}H NMR, δ: 2.02 (s, 3 H, Me); 7.37 (dd, 1 H, H(7), J = 8.2 Hz, J = 1.3 Hz); 7.50—7.65 (m, 2 H, 2 HPh); 7.65—7.70 (m, 1 H, 1 HPh); 7.75 (t, 1 H, H(6), J = 8.0 Hz); 7.96 (d, 1 H, H(3), J = 8.3 Hz); 8.20 (dd, 1 H, H(5), J = 7.8 Hz, J = 1.3 Hz); 8.30 (d, 1 H, H(4), J = 8.3 Hz); 8.25—8.35 (m, 2 H, 2 HPh).

2-Benzoylethynyl-1-benzoyloxyanthraquinone (5). A mixture of iodoanthraquinone **2** (4.54 g, 10 mmol) and cuprous benzoylacetylide (2.22 g, 11.5 mmol) in DMF (200 mL) was refluxed with stirring under argon for 1.5 h, filtered, and poured into $CHCl_3$ (600 mL). The chloroform solution was washed with water and dried with $MgSO_4$. The solvent was distilled off *in vacuo*, and the residue was recrystallized from toluene (110 mL). The yield of ketone **5** was 3.20 g (70%) (see Table 1).

8-Acetoxy-2-benzoylethynyl-1-benzoyloxyanthraquinone (11) was prepared analogously to ketone **5** from iodide **10** (the reaction time was 45 min) in 74% yield (see Table 1).

2-Benzoylethynyl-1-hydroxyanthraquinone (1). Benzoyloxyanthraquinone **5** (2.40 g, 5.3 mmol) in concentrated H_2SO_4 (80 mL) was stirred at 20 °C for 5 min, poured into water (400 mL), and extracted with $CHCl_3$. After removal of the solvent *in vacuo*, the residue was recrystallized from benzene. The yield of compound **1** was 1.80 g (96%) (see Table 1)

2-Benzoylethynyl-1,8-dihydroxyanthraquinone (12). Diacylanthraquinone **11** was deacylated as described above for benzoyl derivative **5** (the reaction time was 15 min). Product **12** was purified by chromatography on SiO_2 using $CHCl_3$ as the eluent; the yield was 71% (see Table 1).

1-Hydroxy-2-(3-oxo-1-piperidino-3-phenylpropenyl)anthraquinone (17). A solution of ketone **1** (1.40 g, 4.0 mmol) in piperidine (50 mL) was stirred at 20 °C for 15 min. The reaction mixture was diluted with $CHCl_3$ (300 mL), washed with water, and dried with $MgSO_4$. The solvent was removed *in vacuo*. Recrystallization from a 1 : 1 benzene—hexane mixture afforded aminovinyl ketone **17** in a yield of 1.55 g (89%), m.p. 209—211 °C. Found (%): C, 76.68; H, 5.19; N, 3.04. $C_{28}H_{23}NO_4$. Calculated (%): C, 76.87; H, 5.30; N, 3.20. ^{1}H NMR, δ: 1.65 (br.s, 6 H, β- and γ-CH_2); 3.38 (br.s, 4 H, NCH_2); 6.16 (s, 1 H, =CH); 7.30—7.40 (m, 3 H, 3 HPh); 7.53 (d, 1 H, H(3), J = 8.0 Hz); 7.88 (d, 1 H, H(4), J = 8.0 Hz); 7.75—7.85 (m, 4 H, 2 HPh, H(6), H(7)); 8.25—8.35 (m, 2 H, H(5), H(8)); 12.99 (s, 1 H, OH). IR, ν/cm^{-1}: 1645, 1680 (C=O).

1-Hydroxy-2-(1-oxo-3-phenylpropynyl)anthraquinone (15). A mixture of compound **17** (0.22 g, 0.5 mmol) and $POCl_3$ (0.15 g, 1 mmol) in dioxane (7 mL) was heated at 80 °C for 80 min, poured into a 10% aqueous KOH solution (10 mL), stirred for 10 min, diluted with water (100 mL), and extracted with $CHCl_3$. After removal of the solvent, the residue (0.10 g) containing two compounds (TLC data) was twice recrystallized from a 1 : 2 benzene—hexane mixture, and ketone **15** was isolated in a yield

of 70 mg (40%) (see Table 1). The second compound present in the crude product was identified as anthrafurantrione **18**.

2-Benzylideneanthra[1,2-*b*]furan-3,6,11-trione (18). A mixture of ketone **15** (75 mg, 0.2 mmol) and cuprous phenylacetylide (66 mg, 0.4 mmol) in anhydrous toluene (20 mL) was heated under argon at 90 °C for 4 h, filtered, concentrated *in vacuo* until crystallization started, and then cooled. Crystals of furanone **18** were filtered off. The yield of compound **18** was 45 mg (60%) (see Table 2).

2-Benzoylanthra[1,2-*b*]furan-6,11-dione (14). ***A.*** A mixture of ketone **1** (110 mg, 0.3 mmol) and cuprous phenylacetylide (50 mg, 0.3 mmol) in pyridine (10 mL) was stirred under argon at 20 °C for 0.5 h, diluted with $CHCl_3$ (100 mL), and washed with dilute HCl and water. After removal of $CHCl_3$, the residue was recrystallized from dichloroethane. Furan **14** was obtained in a yield of 72 mg (68%) (see Table 2).

B. A mixture of iodide **4** (0.41 g, 1.15 mmol) and cuprous benzoylacetylide (0.22 g, 1.15 mmol) in DMF (30 mL) was refluxed with stirring under argon for 1.5 h, filtered, diluted with $CHCl_3$ (200 mL), and washed with water. The solvent was removed *in vacuo*. The residue was recrystallized from dichloroethane. Furan **14** was obtained in a yield of 0.26 g (73%).

2-Phenylanthra[1,2-*b*]pyran-4,7,12-trione (6). ***A.*** 2-Benzoylethynyl-1-benzoyloxyanthraquinone (**5**) (114 mg, 0.25 mmol) in concentrated H_2SO_4 (5 mL) was stirred at 70 °C for 0.5 h, poured into water (200 mL), and extracted with $CHCl_3$ (300 mL). Pyran **6** was obtained in a yield of 78 mg (89%) (see Table 2).

Under the same conditions, pyran **6** was prepared from 2-benzoylethynyl-1-hydroxyanthraquinone (**1**) in 89% yield.

B. A solution of 1-hydroxy-2-(1-oxo-3-phenylpropynyl)anthraquinone (**15**) (105 mg, 0.3 mmol) in piperidine (5 mL) was stirred at 20 °C for 0.5 h, diluted with $CHCl_3$ (100 mL), and washed with water. The resulting chloroform solution of adduct **19** was concentrated *in vacuo* to ~3 mL. Then dioxane (15 mL) and water (1 mL), which was acidified with one drop of concentrated H_2SO_4, were added to the reaction mixture. The mixture was stirred at 80 °C for 45 min, cooled, diluted with $CHCl_3$ (100 mL), washed with water, and dried with $MgSO_4$. Recrystallization from toluene afforded pyran **6** in a yield of 54 mg (51%).

C. A mixture of ketone **15** (0.18 g, 0.5 mmol) and piperidine (0.3 mL, 0.30 g, 3 mmol) in anhydrous benzene (10 mL) was refluxed with stirring for 1 h. After cooling, the precipitate was filtered off, washed with hexane, and chromatographed on SiO_2 in $CHCl_3$. Pyran **6** was obtained in a yield of 0.15 g (83%).

D. A solution of ketone **15** (0.17 g, 0.5 mmol) in piperidine (5 mL) was stirred at 20 °C for 0.5 h, diluted with $CHCl_3$ (150 mL), and washed with water. The chloroform solution of adduct **19** was concentrated to ~60 mL and deposited onto SiO_2 (100 cm^3, 40—100 μm). After 2 h, pyran **6** was eluted with $CHCl_3$; the yield was 0.14 g (82%).

11-Hydroxy-2-phenylanthra[1,2-*b*]pyran-4,7,12-trione (7). Cyclization of 8-acetoxy-2-benzoylethynyl-1-benzoyloxyanthraquinone (**11**) (0.26 g, 0.5 mmol) was carried out analogously to compound **5** in concentrated H_2SO_4 (20 mL) at 80 °C for 1.5 h. Chromatography of the crude product on SiO_2 in $CHCl_3$ afforded hydroxypyran **7** in a yield of 0.13 g (71%) (see Table 2).

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