Photocyclization of 2-azido-1-(4-*tert*-butylphenoxy)-9,10-anthraquinone in the presence of substituted phenols*

L. S. Klimenko, I. A. Os´kina, V. M. Vlasov, I. Yu. Bagryanskaya, and Yu. V. Gatilov*

N. N. Vorozhtsov Novosibirsk Institute of Organic Chemistry, Siberian Branch of the Russian Academy of Sciences, 9 prosp. Akad. Lavrent´eva, 630090 Novosibirsk, Russian Federation. Fax: +7 (383) 330 9752. E-mail: vmvlasov@nioch.nsc.ru

New types of phototransformations in the quinone series, *viz.*, photocyclizations of 1-aryloxy-2-azido-9,10-anthraquinone in the presence of phenols, were studied. The photolysis affords mainly 5*H*-naphtho[2,3-*c*]phenoxazine-8,13-diones, in which the nitrogen atom is covalently bound to the phenyl ring of the attached phenol. As a result, complex polycyclic derivatives of phenoxazines were prepared in high yields in one step.

Key words: photolysis, photocyclization, 9,10-anthraquinones, azides, 5*H*-naphtho[2,3-*c*]phenoxazine-8,13-diones, phenols, X-ray diffraction analysis.

It is known[1,2] that visible light irradiation of 1-aryloxy-9,10-anthraquinone derivatives causes migration of the aryl group to the *peri*-oxygen atom to form highly reactive 9-aryloxy-1,10-anthraquinones. Earlier, we have modified 1-aryloxy-9,10-anthraquinones by introducing the second photoactive (acyloxy,[3] nitroso,[4] diazo, azo,[5] or azido[6,7]) group into the quinone molecule and studied the factors determining the reactivity and the preference of a particular reaction pathway. The photolysis and thermolysis of 2-diazo and azido derivatives proved to be a convenient general approach to the synthesis of new heterocyclic 9,10-anthraquinone derivatives annelated at positions 1 and 2 with furan, thiophene, phenoxazine, or phenothiazine heterocycles. A new photoreaction, *viz.*, the cyclization of 2-azido-1-(4-*tert*-butylphenoxy)-9,10-anthraquinone in the presence of excess 4-*tert*-butylphenol yielding 5*H*-naphtho[2,3-*c*]phenoxazine-8,13-dione substituted at the nitrogen atom, was discovered in the study.[7] To our knowledge, data on analogous photoinitiated cyclizations of azido derivatives are lacking in the literature.

Undoubtedly, a detailed investigation of this cyclization is of theoretical interest because the mechanism of this reaction and the dependence of its efficiency on the chemical nature of the reagents remain unclear. These data can be useful also in the applied aspect because the observed photocyclization is a new one-step synthesis of various polycyclic phenoxazines and phenothiazines.

The aim of the present study was to investigate photochemical transformations of 2-azido-1-(4-*tert*-butylphenoxy)-9,10-anthraquinone in the presence of phenol and its alkyl derivatives, compare the efficiency of the phototransformations, and determine the structures of photocyclization products.

Results and Discussion

2-Azido-1-(4-*tert*-butylphenoxy)-9,10-anthraquinone (**1**) was synthesized from 2-amino-1-chloro-9,10-anthraquinone by introducing the 4-*tert*-butylphenoxy group according to a known procedure[8] followed by the diazotization of the amino group and the reaction of the resulting solution of the diazonium salt with NaN_3 by analogy with the study.[9]

A solution of azidoanthraquinone **1** and phenol ArOH in a ratio of 1 : 3 in dry benzene was irradiated at 20 °C with full light from a mercury lamp or with sunlight until azide **1** was completely consumed (Scheme 1). The photocyclization in the presence of unsubstituted phenol or *ortho*- and *para*-alkyl-substituted phenols afforded the corresponding 5*H*-naphtho[2,3-*c*]phenoxazine-8,13-diones **2a—d** in high yields. In all cases, small amounts (<5%) of 1-hydroxy-2-(4-*tert*-butylphenylamino)-9,10-anthraquinone were detected in photolysates by analogy with the study.[7]

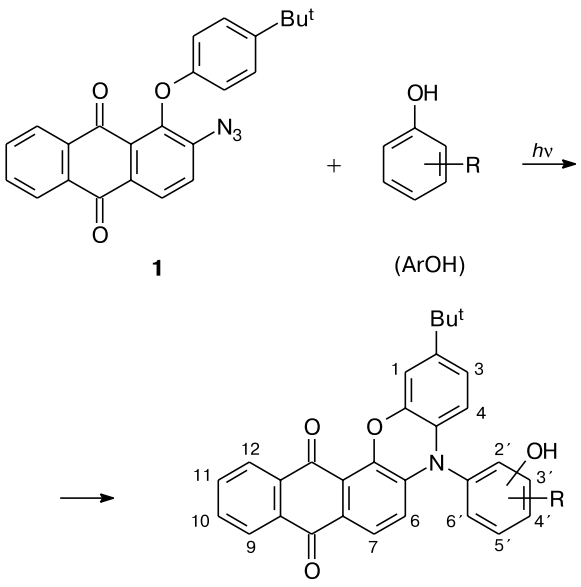
The structures of phenoxazines **2a—d** were determined by elemental analysis, mass spectrometry, and IR, UV, and ^{1}H NMR spectroscopy. When assigning the signals in the ^{1}H NMR spectra of compounds **2a—d** (see the Experimental section), we found signals for six protons of the anthraquinone moiety, *viz.*, the characteristic pairs of signals for the protons H(10), H(11) and H(9), H(12) of the unsubstituted anthraquinone ring and two signals for

* Dedicated to the memory of Academician N. N. Vorozhtsov on the 100th anniversary of his birth.

Published in Russian in *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 6, pp. 1089—1093, June, 2007.

1066-5285/07/5606-1130

Scheme 1



Ar in ArOH	**2**	OH	R	*t*/h	Yield (%)
Ph	**a**	4′	H	4.5	87
4-MeC_6H_4	**b**	2′	5′-Me	3.5	82
2,6-$Me_2C_6H_3$	**c**	4′	3′,5′-Me_2	3.0	86
4-$Bu^tC_6H_4$	**d**	2′	5′-Bu^t	4.0	79

the protons H(6) and H(7) of the substituted ring. The ^{1}H NMR spectra of products **2b,d** obtained by the photocyclization with *para*-substituted phenols show two set of signals, each set corresponding to three aromatic protons (H(1), H(3), H(4) and H(3′), H(4′), H(6′)) with the splitting pattern being typical of 1,2,4-trisubstituted benzenes.[10] This is evidence for the attachment of the nitrogen atom at the *ortho* position with respect to the hydroxy group. In the ^{1}H NMR spectra of compounds **2a,c**, the signals for the protons H(2′), H(3′), H(5′), H(6′) and H(2′), H(6′) appear as a broad singlet and a singlet, respectively, which is indicative of the replacement of the hydrogen atom in the *para* position of the aromatic ring of phenol. To prove the position of the *tert*-butyl substituent in the aromatic ring of the phenoxazine fragment, we studied compound **2c** by X-ray diffraction.

The three-dimensional structure of compound **2c** is shown in Fig. 1. The pentacyclic moiety of the molecule is virtually planar (the rms deviation from the plane is 0.109 Å). However, although the phenyl rings are planar within 0.006—0.044 Å, the O(14) and N(5) atoms in the oxazine ring deviate in the same direction from the plane passing through the other four C atoms of the oxazine ring by 0.072 and 0.064 Å, respectively. The geometric parameters of molecule **2c** are within 3σ of the mean values.[11] It should be noted that we found no structures containing a similar pentacyclic moiety in the Cambridge Structural Database.[12] The most similar compounds containing the phenoxazine moiety, such as 2-methyl-2-(10-phenoxazinyl)propionitrile,[13] 10-piperidylacetylphenoxazine,[14] 10-acetyl-1-cyanophenoxazine,[15] and 10-acetyl-3-cyanophenoxazine,[16] are nonplanar, and the oxazine ring in these compounds adopts a boat conformation. The bond lengths and bond angles in the phenoxazine fragment of molecule **2c** are similar to the corresponding parameters in the above-mentioned compounds. The N(5)—C(4a) and N(5)—C(5a) bond lengths are the only exceptions. In molecule **2c**, these bonds are shortened to 1.392(6) and 1.396(6) Å compared to the analogous bonds in the reference compounds (from 1.426 to 1.455 Å). Presumably, this difference is associated with a flattening of the oxazine ring in molecule **2c**. The plane passing through the atoms of the phenyl ring C(1′)—C(6′) (the rms deviation from the plane is 0.006 Å) is virtually perpendicular to the plane of the pentacyclic moiety (the dihedral angle between these two fragments is 82.4(1)°).

In the crystal structure of compound **2c**, the molecules are linked to each other by the O(3)—H...O(2) hydrogen bonds (O(3)...O(2), 2.864(6) Å; H...O, 1.93(6) Å; O(3)—H...O, 154(4)°) to form infinite head-to-tail chains along the *b* axis. The chains are linked in pairs by π-stacking arene—arene interactions (Fig. 2). The distance between the planes of the adjacent molecules involved in the π-stacking interactions is 3.56 Å; the intercenter distance between the 1,4-benzoquinone and oxazine rings is 3.568(3) Å. The pairs of chains are packed in stacks along the *a* axis with the distance of 3.45 Å between the planes of the adjacent molecules. The intercenter distances vary from 3.934(3) to 4.133(4) Å, which is indicative of a large shift of the π-stacking interaction.

The X-ray diffraction data provide unambiguous evidence that the cyclization under study is accompanied by a change in the position of the *tert*-butyl substituent in the phenoxazine ring. The substituent, which is in the *para* position with respect to the oxygen atom in the aryloxy group of starting azide **1**, is attached at the *para* position with respect to the nitrogen atom in the reaction products. In earlier studies[17—19] on the photolysis and thermolysis of isomeric 2-aryloxy-1-azido-9,10-anthraquinones, the same change in the position of the substituent was demonstrated by the independent synthesis.

Our experimental data are not contradictory to the commonly accepted mechanism of photocyclization of aryl azides containing an arylthio or aryloxy group in the *ortho* positions with respect to the azido group[7,17—20] (Scheme 2). According to the published data, the carbon atom of the substituent bound to the heteroatom is attacked by singlet nitrene **3** that is generated upon photodecomposition of the azido group[21] to form intermediate

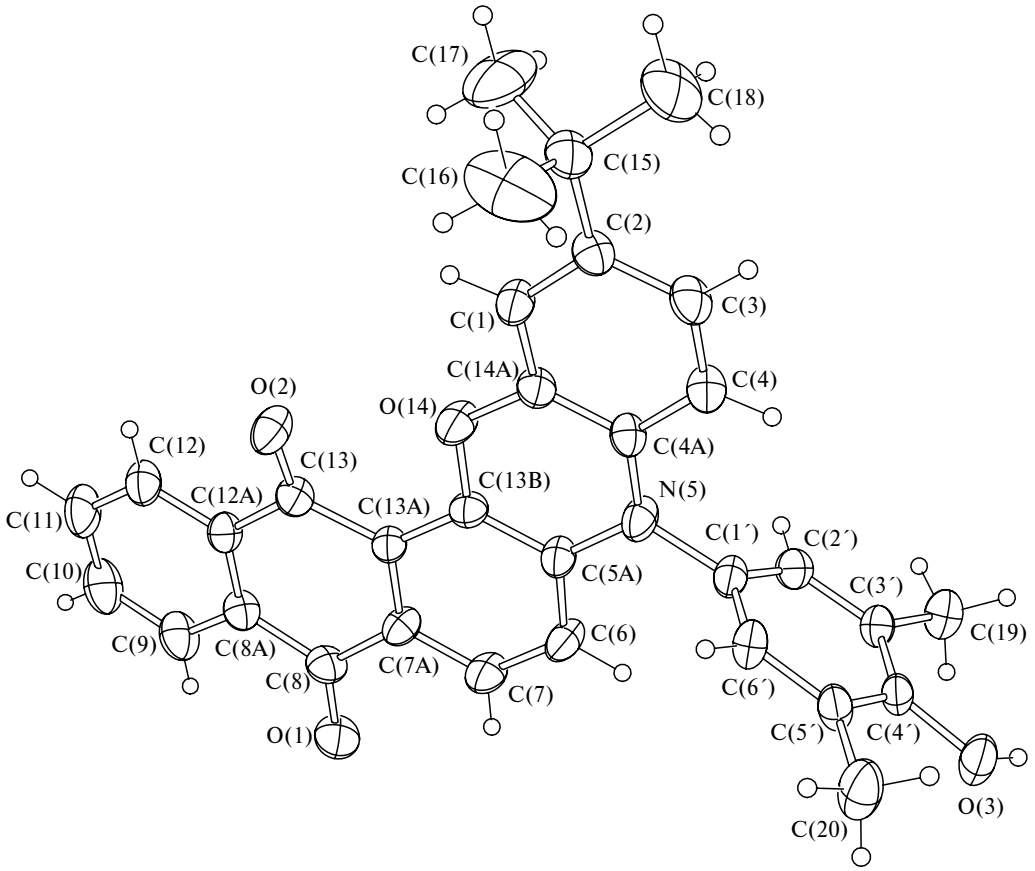


Fig. 1. Three-dimensional structure of 2-*tert*-butyl-5-(4′-hydroxy-3′,5′-dimethylphenyl)naphtho[2,3-*c*]phenoxazine-8,13-dione (**2c**) based on X-ray diffraction data.

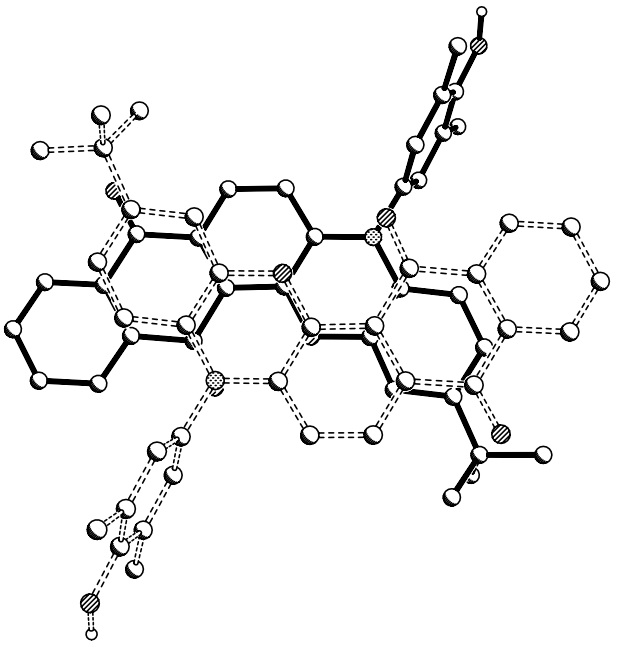
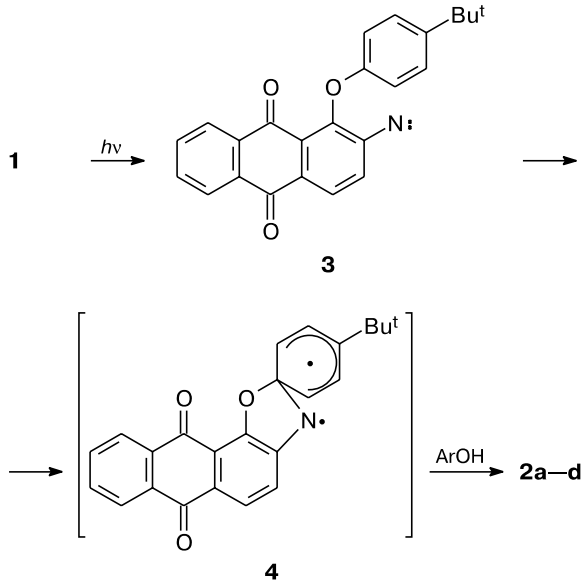


Fig. 2. π-Stacking interactions between molecules **2c** in the adjacent chains based on X-ray diffraction data (the projection along the crystallographic direction [101]).

Scheme 2



biradical spiro complex **4**. The formation of phenoxazines **2a—d** upon irradiation of azide **1** in the presence of sub-

stituted phenols can be attributed to the radical substitution of the hydrogen atom in phenol derivatives by this intermediate biradical spiro complex. The experimentally observed direction of the attack (*ortho* and *para* positions) is consistent with the known features of the free-radical aromatic substitution.[22,23]

To summarize, we studied a new type of photochemical transformations in the quinone series, *viz.*, the photocyclization of 1-aryloxy-2-azido-9,10-anthraquinones in the presence of phenols. 5*H*-Naphtho[2,3-*c*]phenoxazine-8,13-diones, in which the nitrogen atom is covalently bound to the phenyl ring of the introduced reagent, were prepared in high yield. The present study demonstrated that the above-described photocyclization provides a convenient one-step procedure for the synthesis of various *N*-substituted polycyclic derivatives of phenoxazine.

Experimental

The IR spectra were recorded on a Vector-22 (Bruker) spectrophotometer in KBr pellets. The UV-Vis spectra were measured on a Hewlett Packard Agilent 8453 spectrophotometer in ethanol ($1 \cdot 10^{-4}$ mol L^{-1}). The ^1H NMR spectra were recorded on a Bruker WP-200SY instrument (the chemical shifts are given on the δ scale) with $SiMe_4$ as the internal standard. The EI mass spectra were obtained on a Finnigan MAT-8200 instrument. The TLC analysis was carried out on Silufol UV-254 plates using a 9 : 1 toluene—ethanol system as the eluent. The column chromatography was carried out on silica gel (140—350 μm). The solvents were dried before use. Photolysis was carried out using light from a SVD-120A lamp through an UFS-1 light filter (280—400 nm) and also with the use of the full spectrum of the mercury lamp. The synthesis and physicochemical characteristics of the starting azidoanthraquinone **1** have been described earlier.[7]

Preparative photolysis of azide 1 in the presence of phenols (general procedure). A solution of compound **1** (0.4 g, 1 mmol) and substituted phenol (3 mmol) in dry benzene (0.5 L) was irradiated at 20 °C for 3—4.5 h until the starting compound disappeared (TLC monitoring). The reaction solution was concentrated, and the residue was chromatographed on silica gel. 1-Hydroxy-2-(4-*tert*-butylphenyl)amino-9,10-anthraquinone (0.01—0.02 g) was isolated from the first violet band by elution with benzene. This product was identified by comparing with an authentic sample.[8] Then the major violet band was eluted with chloroform. Products **2a—d** were recrystallized from an ethanol—benzene mixture.

2-*tert*-Butyl-5-(4′-hydroxyphenyl)-5*H*-naphtho[2,3-*c*]phenoxazine-8,13-dione (2a). M.p. 236—239 °C. ^1H NMR ($CDCl_3$), δ: 1.23 (s, 9 H, Bu^t); 5.92 (d, 1 H, H(4), J = 8.5 Hz); 6.13 (d, 1 H, H(6), J = 8.5 Hz); 6.66 (dd, 1 H, H(3), J_1 = 8.5 Hz, J_2 = 3.0 Hz); 6.86 (br.s, 1 H, OH); 7.03 (d, 1 H, H(1), J = 3.0 Hz); 7.14 (br.s, 4 H, H(2′), H(3′), H(5′), H(6′)); 7.60 (d, 1 H, H(7), J = 8.5 Hz); 7.73 (m, 2 H, H(10), H(11)); 8.25 (m, 2 H, H(9), H(12)). IR, ν/cm^{-1}: 3467 (OH); 3010, 2949, 2864 (C—H); 1666 (C=O); 1590, 1514 (C=C). UV-Vis, λ_{max}/nm (logε): 266 (4.72), 314 (3.63), 405 (3.46), 562 (4.00). High-resolution mass spectrum, found: m/z 461.1635 [M^+]. $C_{30}H_{23}NO_4$. Calculated: M = 461.1627.

2-*tert*-Butyl-5-(2′-hydroxy-5′-methylphenyl)-5*H*-naphtho[2,3-*c*]phenoxazine-8,13-dione (2b). M.p. 238—241 °C. Found (%): C, 78.00; H, 5.36; N, 3.09. $C_{31}H_{25}NO_4$. Calculated (%): C, 78.32; H, 5.26; N, 2.95. ^1H NMR ($CDCl_3$), δ: 1.23 (s, 9 H, Bu^t); 2.30 (s, 3 H, Me); 5.97 (d, 1 H, H(3′), J = 8.5 Hz); 4.57 (br.s, 1 H, OH); 6.09 (d, 1 H, H(6), J = 8.5 Hz); 6.72 (dd, 1 H, H(4′), J_1 = 8.5 Hz, J_2 = 3.0 Hz); 6.82 (d, 1 H, H(6′), J = 3.0 Hz); 6.98 (d, 1 H, H(1), J = 3.0 Hz); 7.02 (d, 1 H, H(4), J = 8.5 Hz); 7.12 (d, 1 H, H(7), J = 8.5 Hz); 7.45 (dd, 1 H, H(3), J_1 = 8.5 Hz, J_2 = 3.0 Hz); 7.66 (m, 2 H, H(10), H(11)); 8.10 (m, 2 H, H(9), H(12)). IR, ν/cm^{-1}: 3430 (OH); 3035, 2963 (C—H); 1664 (C=O); 1590, 1522 (C=C). UV-Vis, λ_{max}/nm (logε): 268 (4.70), 313 (3.64), 403 (3.48), 560 (3.98). MS, m/z: 475 [M^+].

2-*tert*-Butyl-5-(4′-hydroxy-3′,5′-dimethylphenyl)-5*H*-naphtho[2,3-*c*]phenoxazine-8,13-dione (2c). M.p. 325—327 °C. ^1H NMR ($CDCl_3$), δ: 1.23 (s, 9 H, Bu^t); 2.29 (s, 6 H, 2 Me); 5.10 (br.s, 1 H, OH); 5.92 (d, 1 H, H(4), J = 8.5 Hz); 6.17 (d, 1 H, H(6), J = 8.5 Hz); 6.66 (dd, 1 H, H(3), J_1 = 8.5 Hz, J_2 = 3.0 Hz); 6.90 (s, 2 H, H(2′), H(6′)); 7.00 (d, 1 H, H(1), J = 3.0 Hz); 7.63 (d, 1 H, H(7), J = 8.5 Hz); 7.72 (m, 2 H, H(10), H(11)); 8.25 (m, 2 H, H(9), H(12)). IR, ν/cm^{-1}: 3485 (OH); 3078, 2960, 2873 (C—H); 1664 (C=O); 1597, 1516 (C=C). UV-Vis, λ_{max}/nm (logε): 264 (4.78), 313 (3.60), 405 (3.61), 560 (3.90). High-resolution mass spectrum, found: 489.1951 [M^+]. $C_{32}H_{27}NO_4$. Calculated: M = 489.1940.

2-*tert*-Butyl-5-(5′-*tert*-butyl-2′-hydroxyphenyl)-5*H*-naphtho[2,3-*c*]phenoxazine-8,13-dione (2d). M.p. 192—195 °C. ^1H NMR (500 MHz, $CDCl_3$), δ: 1.22 and 1.29 (both s, 9 H each, 2 Bu^t); 5.94 (d, 1 H, H(3′), J = 8.5); 5.99 (d, 1 H, H(6), J = 8.5 Hz); 6.68 (dd, 1 H, H(4′), J_1 = 8.5 Hz, J_2 = 3.0 Hz); 6.70 (d, 1 H, H(6′), J = 3.0 Hz); 7.14 (d, 1 H, H(1), J = 3.0 Hz); 7.18 (d, 1 H, H(4), J = 8.5 Hz); 7.31 (d, 1 H, H(7), J = 8.5 Hz); 7.44 (dd, 1 H, H(3), J_1 = 8.5 Hz, J_2 = 3.0 Hz); 7.59 (td, 1 H, H(10), J_1 = 8.0 Hz, J_2 = 2.0 Hz); 7.66 (td, 1 H, H(11), J_1 = 8.0 Hz, J_2 = 2.0 Hz); 7.75 (br.s, 1 H, OH); 8.00 (dd, 1 H, H(9), J_1 = 8.0 Hz, J_2 = 2.0 Hz); 8.05 (dd, 1 H, H(12), J_1 = 8.0 Hz, J_2 = 2.0 Hz). IR, ν/cm^{-1}: 3400 (OH); 2960 (C—H); 1660 (C=O), 1590, 1522 (C=C). UV-Vis, λ_{max}/nm (logε): 266 (4.78), 313 (3.63), 410 (3.46), 560 (4.02). High-resolution mass spectrum, found: 517.2241 [M^+]. $C_{34}H_{32}NO_4$. Calculated: M = 517.2253.

X-ray diffraction study of compound 2c. X-ray diffraction data were collected on a Bruker P4 diffractometer (Mo-Kα radiation, graphite monochromator, 2θ/θ-scanning technique in the range $2\theta < 50°$). A crystal of compound **2c** of dimensions 0.60×0.36×0.03 mm was selected. The crystals are monoclinic: a = 10.095(2) Å, b = 20.326(5) Å, c = 12.952(4) Å, β = 110.32(2)°, V = 2492(1) $Å^3$, space group $P2_1/c$, Z = 4, $C_{32}H_{27}NO_4$, d_{calc} = 1.305 g cm^{-3}, μ = 0.086 mm^{-1}. The intensities of 4370 independent reflections were measured. The empirical absorption correction was applied based on azimuthal scans (the transmission was 0.79—0.98). The structure was solved by direct methods using the SHELXS-97 program package[16] and refined by the full-matrix least-squares method with anisotropic displacement parameters for nonhydrogen atoms and isotropic displacement parameters for H atoms using the SHELXL-97 program package.[16] The parameters of other H atoms (except for OH) were calculated in each refinement cycle from the coordinates of the corresponding carbon atoms. The hydrogen atom of the hydroxy group at the O(3) atom was located in a difference electron density map. The final refinement was carried out based on all F^2 to wR_2 = 0.1926, S = 0.905, 339 variables

(R = 0.0734 for 1490 reflections with $F > 4\sigma$). The structure of **2c** was deposited at the Cambridge Crystallographic Data Centre (CCDC, refcode 626170). The X-ray diffraction data can be obtained free of charge *via* http://www.ccdc.cam.ac.uk/data_request/cif deposit.

References

1. N. P. Gritsan and L. S. Klimenko, *J. Photochem. Photobiol. A: Chem.*, 1992, **70**, 103.
2. V. A. Barachevsky, in *Organic Photochromic and Termochromic Compounds*, Eds J. C. Crano and R. Guglielmetti, Plenum Press, New York, 1999, **1**, 267.
3. N. P. Gritsan, L. S. Klimenko, E. M. Shvartsberg, I. V. Khmelinski, and E. P. Fokin, *J. Photochem. Photobiol. A: Chem.*, 1990, **52**, 137.
4. L. S. Klimenko and E. P. Fokin, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1991, 2098 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1991, **40**, 1858 (Engl. Transl.)].
5. L. S. Klimenko, I. Ya. Mainagashev, and E. P. Fokin, *Izv. Akad. Nauk, Ser. Khim.*, 1992, 582 [*Bull. Russ. Acad. Sci., Div. Chem. Sci.*, 1992, **41**, 459 (Engl. Transl.)].
6. L. S. Klimenko, E. A. Pritchina, and N. P. Gritsan, *Izv. Akad. Nauk, Ser. Khim.*, 2001, 652 [*Russ. Chem. Bull., Int. Ed.*, 2001, **50**, 678].
7. L. S. Klimenko, E. A. Pritchina, and N. P. Gritsan, *Chem. Eur. J.*, 2003, **9**, 1639.
8. E. P. Fokin, S. A. Russkikh, and L. S. Klimenko, *Izv. Sib. Otd. Akad. Nauk, Ser. Khim.*, 1978, **7**, 110 [*Izv. Sib. Branch Akad. Nauk SSSR, Ser. Khim. Nauk*, 1978, **7** (Engl. Transl.)].
9. L. M. Gornostaev, V. A. Levdanskii, and E. P. Fokin, *Zh. Org. Khim.*, 1979, **15**, 1692 [*J. Org. Chem. USSR*, 1979, **15** (Engl. Transl.)].
10. I. P. Klimenko, V. A. Korolev, Yu. V. Tomilov, and O. M. Nefedov, *Zh. Org. Khim.*, 2006, **42**, 1320 [*Russ. J. Org. Chem.*, 2006, **42**, 1299 (Engl. Transl.)].
11. F. H. Allen, O. Kenard, D. G. Watson, L. Bramer, A. G. Orpen, and R. Taylor, *J. Chem. Soc., Perkin Trans. 2*, 1987, **12**, 21.
12. F. H. Allen, *Acta Crystallogr., Sect. B*, 2002, **58**, 380 (Version 5.27).
13. D. Gigmes, D. Siri, J.-P. Reboul, N. Redouane, P. Tordo, and G. Pepe, *Acta Crystallogr., Sect. C: Cryst. Struct. Commun.*, 1998, **54**, 822.
14. M. A. Sridhar, M. Ramegowda, N. K. Lokanath, J. S. Prasad, G. B. E. Gowda, and K. N. Thimmaiah, *Mol. Cryst. Liq. Cryst. Sci. Technol., Sect. A*, 1999, **326**, 189.
15. G. C. Eastmond, T. L. Gilchrist, J. Paprotny, and A. Steiner, *New J. Chem.*, 2001, **25**, 385.
16. G. M. Sheldrick, *SHELX-97 (Release 97-2), Program for the Refinement of Crystal Structure*, Göttingen University, Göttingen (Germany), 1998.
17. F. M. Dmitriev, L. M. Gornostaev, N. P. Gritsan, and A. V. El´tsov, *Zh. Org. Khim.*, 1985, **21**, 2452 [*J. Org. Chem. USSR*, 1985, **21**, 2587 (Engl. Transl.)].
18. A. V. El´tsov, F. M. Dmitriev, L. M. Gornostaev, and N. I. Rtishchev, *Zh. Org. Khim.*, 1986, **22**, 2361 [*J. Org. Chem. USSR*, 1986, **22**, 2357 (Engl. Transl.)].
19. L. M. Gornostaev, I. A. Kuznetsov, and N. P. Gritsan, *Zh. Org. Khim.*, 1991, **27**, 389 [*J. Org. Chem. USSR*, 1991, **27** (Engl. Transl.)].
20. L. S. Klimenko, S. Z. Kusov, V. M. Vlasov, E. N. Tchabueva, and V. V. Boldyrev, *Mendeleev Commun.*, 2006, 224.
21. N. P. Gritsan and M. S. Platz, *Chem. Rev.*, 2006, **106**, 3844.
22. A. S. Dneprovskii, *Teoreticheskie osnovy organicheskoi khimii* [*Theoretical Foundations of Organic Chemistry*], Khimiya, Leningrad, 1991, 560 pp. (in Russian).
23. S. V. Volovik, G. G. Dyadyusha, and V. I. Stanivets, *Regioselektivnost´ i reaktsionnaya sposobnost´ svobodnykh radikalov v protsessakh prisoedineniya i aromaticheskogo zameshcheniya* [*Regioselectivity and Reactivity of Free Radicals in Coupling and Aromatic Substitution Processes*], Naukova Dumka, Kiev, 1988, 112 pp. (in Russian).

Received January 19, 2007