POLYFURYL(ARYL)ALKANES AND THEIR DERIVATIVES. 10.* SELECTIVE SYNTHESIS OF 2-HYDROXY-ARYLDIFURYLMETHANES

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It was shown that Me_3SiCl , $B(OH)_3$, $PhB(OH)_2$, and B_2O_3 can act as catalysts for the selective synthesis of 2-hydroxyaryldifurylmethanes. It was established by x-ray crystallographic analysis that the molecules in the crystal of 2-hydroxy-3,5-diiodophenylbis(5-methyl-2-furyl)methane are linked in pairs by two hydrogen bonds between the hydroxyl group in one of them and the oxygen atom of the furyl group in the other.

Earlier we reported that the condensation of salicylaldehyde and its substituted derivatives (Ia-c) with sylvane in benzene in the presence of perchloric acid is accompanied by recyclization of the 2-hydroxyaryldifurylmethanes formed here into benzofuran derivatives and by further cyclization of the latter to derivatives of 5,6-dihydro-4H-benzo[b]furo[2,3-h]cyclohepta[b]furan [2, 3]. For this reason the yield of compounds (III) was low (e.g., see Table 1), and the isolation of the final products involved some difficulties, requiring the use of column chromatography. (We note that an increase in the rate of the side reactions must be expected with increase in the acidity of the medium.) The exception was substituted 3-nitrosalicylaldehydes, which only gave products of type (III) during condensation with sylvane. We explained this fact by the presence of an intramolecular hydrogen bond between the OH group and the oxygen atom of the nitro group, which prevented recyclization [3].



In order to reduce the above-mentioned side reactions to a minimum, we tried to select mild catalysts that would secure the selective condensation of the aldehydes (Ia-c) with sylvane (II) and the preferential formation of the products (IIIa-c) (Scheme 1). The use of $Mg(ClO_4)_2$, which was proposed earlier for the synthesis of aryldifurylmethanes [4], did not give any advantages compared with perchloric acid. It was reported in the literature that the reaction of salicylaldehyde with sylvane

Severo-Osetinsk State University, Vladikavkaz. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 2, pp. 162-167, February, 1996. Original article submitted November 27, 1995.

^{*}For Communication 9, see [1].

Compound	Yield, %				
	HClO ₄ [3]	Me3SiCl	B2O3. B(OH)3	PhB(OH)2	
IIIa	21	90	5	5	
IIIb	12	65	50	36	
IIIc	24	45	48	38	

TABLE 1. Yields of Compounds (IIIa-c) in Relation to the Employed Catalyst



Fig. 1. Projection of the stereochemical model of the molecule of 3,5-diiodo-2-hydroxyphenylbis(5-methyl-2-furyl)methane (Id).



Fig. 2. Fragment of the packing of the molecules of 3,5diiodo-2-hydroxyphenylbis(5-methyl-2-furyl)methane (Id) in the crystal.

in the presence of the strongly acidic ion-exchange resin Amberlist 15 led to a high yield of 2-hydroxyphenyldifurylmethane [5]. We realized this reaction both in dioxane and in benzene and showed that side transformations take place in both cases.

The best results were obtained with Me_3SiCl as catalyst. Thus, in the presence of the latter the condensation of salicylaldehyde (Ia) with sylvane in benzene was complete after 20-30 min, and the yield of the product (IIIa) amounted to 90% (Table 1).

Atom	.x	у	:	U(eq)
I(1)	9329(1)	8515(1)	7365(1)	43(1)
I(2)	10360(1)	7957(1)	4757(1)	53(1)
0(1)	4771(7)	922(6)	5825(2)	44(2)
O(2)	3026(6)	4566(6)	6280(2)	36(2)
O(3)	6996(7)	4866(6)	5010(2)	41 (2)
C(1)	5654(10)	2298(8)	6105(3)	31 (3)
C(2)	5466(12)	-46(9)	6008(4)	48(3)
C(3)	6689(10)	606(10)	6385(4)	43(3)
C(4)	6787(9)	2158(9)	6444(3)	39(3)
C(5)	4772(18)	-1667(11)	5719(5)	80(5)
C(6)	1787(9)	4305(9)	6681(3)	40(3)
C(7)	1592(10)	3064(11)	7031(4)	43(3)
C(8)	2890(10)	2538(10)	6824(3)	44(3)
C(9)	3724(8)	3504(8)	6385(3)	32(3)
C(10)	875(11)	5306(11)	6644(5)	63(4)
C (11)	5086(9)	3604(8)	5983(3)	30(3)
C(12)	6559(9)	5127(8)	6009(3)	31 (3)
C(13)	7069(9)	5975(8)	6536(3)	32(3)
C(14)	8455(8)	7349(8)	6551(3)	34(3)
C(15)	9371(10)	7936(9)	6038(3) *	39(3)
C(16)	8907(9)	7124(9)	5523(3)	36(3)
C(17)	7536(8)	5732(8)	5494(3)	30(3)

TABLE 2. Coordinates of the Nonhydrogen Atoms ($\dot{A} \times 10^4$) and the Temperature Factors ($\dot{A}^2 \times 10^3$) of the Molecules of Compound (Id)

As we suppose, the first stage of the reaction is the coordination of Me_3SiCl with the carbonyl group of the aldehyde in view of the high strength of the Si-O bond. The obtained complex is sufficiently electrophilic for attack on the furan ring (Scheme 2). The next step is normal electrophilic substitution in the furan ring by the arylfurylcarbenium ion. Since the more acidic hydrogen chloride is produced during the reaction, the process is autocatalytic in nature.

Scheme 2



The hydrogen chloride is partially removed from the organic layer by the water that appears during condensation according to Scheme 1, and this reduces the side recyclization to a minimum. However, increase in the reaction time leads to some accumulation of the recyclization products as a result of the increase in the amount of hydrogen chloride in the reaction medium. We emphasize that Me_3SiCl is a universal catalyst and can be used in the synthesis of other aryldifurylmethanes.

Boric acid derivatives can also be used as catalysts of the investigated reaction. An attempt to obtain a derivative of 2-hydroxyphenylfurylcarbinol by the condensation of 5-nitrosalicylaldehyde with sylvane in the presence of phenylboric acid, by analogy with [6], was unsuccessful, and compound (Ib) was obtained instead of the carbinol. It was found that boric acid itself and its anhydride have the same catalytic properties. The reaction is very selective, and only salicylaldehydes enter into it. This may be due to the formation of a chelate complex between the aldehyde and the boric acid (Scheme 3).

However, while having an undisputed advantage over other catalysts (the complete absence of side products, including resinification of the reaction mixture), the derivatives of boric acid have a substantial disadvantage, i.e., high sensitivity to the effects of the substituents. Thus, for example, the product (Ia) is obtained with very low yield from salicylaldehyde (Table 1).



In the IR spectra of 2-hydroxyaryldifurylmethanes (IIIa-c), recorded in Vaseline oil, the stretching vibrations of the hydroxyl group are represented by a narrow band in the region of 3350-3470 cm⁻¹, indicating that the OH group participates in the formation of only one type of hydrogen bond, as reported earlier [3]. In order to determine the nature of these hydrogen bonds, we undertook an x-ray crystallographic analysis of a single crystal of 2-hydroxy-3,5-diiodophenylbis(5-methyl-2-furyl)methane (Id), obtained by the iodination of compound (Ia). A projection of a molecular model of the diiodide (Id) is shown in Fig. 1, and the atomic coordinates, bond lengths, and bond angles are given in Tables 2-4. The results of the analysis showed that the molecules of compound (Id) in the crystal are linked in pairs by two hydrogen bonds between the hydroxyl group in one molecule and the oxygen atom of one of the furan rings in the other (Fig. 2). The hydrogen bond has the following parameters: $C_{(2)} - H_{(30A)}$ bond length 2.215 Å, $O_{(3A)}H_{(30A)}O_{(2)}$ angle 175.3 Å. The furan ring $O_{(2)}C_{(6)}C_{(7)}C_{(8)}C_{(9)}$ is planar (average deviation 0.0102 Å). The $H_{(30A)}$, $O_{(3A)}$, and $C_{(17A)}$ atoms are separated from this plane by 1.313, 1.722, and 2.959 Å respectively. We note also that the $O_{(2)}$ oxygen atom projects by 0.016 Å on the same side of the plane as the other atoms participating in the formation of the $O_{(3A)} - H_{(30A)} \cdots O_{(2)}$ hydrogen bond.

EXPERIMENTAL

The reaction path and the individuality of the substances were monitored by TLC on Silufol UV-254 plates with the following eluants: 6:1:1 hexane-chloroform-acetone [for (Ia)]; 4:1:1 hexane-chloroform-acetone [for (Ib)]; 3:1 hexane-chloroform [for (Ic) and (Id)]. The chromatograms were developed with iodine vapor.

X-Ray Crystallographic Investigation of 2-Hydroxy-3,5-diiodophenylbis(5-methyl-2-furyl)methane (Id). The monoclinic crystals of compound (Id) with the composition $C_{17}H_{14}I_2O_3$ were grown from a 5:1 mixture of hexane and chloroform. The unit cell parameters were as follows: a = 8.677(3), b = 9.443(3), c = 22.559(4) Å, V = 1691.9(1.7) Å³. The space group is P21/a, z = 4. The unit cell parameters and the intensities of 2075 unique reflections with $I > 2\delta(I)$ were obtained on an Enraf-Nonius CAD-4 automatic diffractometer without a monochromator (MoK α radiation, $\theta/2\theta$ scan to $2\theta = 45^{\circ}$. The structure was interpreted by the direct method using the SHELXTL software [7] and was refined in anisotropic (isotropic for the hydrogen atoms) approximation to R = 0.064 and $R_W = 0.069$. The coordinates of the hydrogen atoms can be obtained from the authors.

2-Hydroxyarylbis(5-methyl-2-furyl)methanes (Ia-c). A. To a solution of 0.10 mole of the derivative of salicylaldehyde and 0.22 mole of sylvane in 28-80 ml of benzene (the amount of benzene depends on the solubility of the aldehyde) we added 1-1.5 ml of trimethylsilyl chloride. After 10-20 min the mixture heated, and water was released. After 1 h the organic layer was filtered through silica gel, the filtrate was evaporated, and the product (I) was obtained by crystallization of the residue.

B. To 0.10 mole of the aldehyde and 0.22 mole of sylvane in 50 ml of benzene we added 50-100 mg or $B(OH)_3$, PhB(OH)₂, or B₂O₃. The obtained mixture was boiled with a Dean-Stark tube for 2 h, after which the solution was cooled and filtered through silica gel. The filtrate was evaporated, and the residue was recrystallized.

The yields of the products (Ia-c) are given in Table 1. The physicochemical characteristics of these compounds correspond to published data [3].

2-Hydroxy-3,5-diiodophenylbis(5-methyl-2-furyl)methane (Id). To a solution of 2.7 g (0.01 mole) of compound (Ia) in 50 ml of ethanol we added 1.0 g (0.025 mole) of sodium hydroxide in the smallest amount of water. While stirring, we then added in small portions 5.1 g (0.02 mole) of finely ground iodine. (An oil may separate toward the end of the addition, and

Bond	ι. Å	Bond	LÅ
	2 1 1 7 (7)	Im Can	2 007 (7)
$O_{(1)} - C_{(1)}$	1,369(8)	O(1) - C(2)	1,35(1)
O(2)-C(6)	1,350(9)	$O_{(2)} - C_{(9)}$	1,38(1)
O(3)-C(17)	1,330(8)	C(1)-C(4)	1,29(1)
$C_{(1)} - C_{(11)}$	1,53(1)	$C_{(2)} - C_{(3)}$	1,30(1)
$C_{(2)} - C_{(5)}$	1,55(1)	$C_{(3)} - C_{(4)}$	1,44(1)
$C_{(6)} - C_{(7)}$	1,37(1)	$C_{(0)} - C_{(10)}$	1,46(2)
$C_{(7)} - C_{(8)}$	1,48(2)	$C_{(8)} - C_{(9)}$	1,34(1)
$C_{(9)} - C_{(11)}$	1,46(1)	$C_{(11)} - C_{(12)}$	1,492(8)
$C_{(12)} - C_{(13)}$	1,40(1)	$C_{(12)} - C_{(17)}$	1,417(9)
$C_{(13)} - C_{(14)}$	1,369(8)	$C_{(14)} - C_{(15)}$	1,39(1)
$C_{(15)} - C_{(16)}$	1,36(1)	$C_{(16)} - C_{(17)}$	1,374(9)

TABLE 3. Bond Lengths in the Molecule of Compound (Id)

TABLE 4. Bond Angles in the Molecule of Compound (Id)

Angle	ω. deg	Angle	ω. deg
$C_{(1)} - O_{(1)} - C_{(2)}$	105,8(6)	$C_{(6)} - O_{(2)} - C_{(9)}$	107,6(6)
$O_{(1)} - C_{(1)} - C_{(4)}$	109,5(8)	$O_{(1)} - C_{(1)} - C_{(11)}$	• 116,4(7)
$C_{(4)} - C_{(1)} - C_{(11)}$	134,1(7)	$O_{(1)} - C_{(2)} - C_{(3)}$	112,3(8)
$O_{(1)} - C_{(2)} - C_{(5)}$	116,2(8)	$C_{(3)} - C_{(2)} - C_{(5)}$	131,4(11)
$C_{(2)} - C_{(3)} - C_{(4)}$	104,2(9)	$C_{(1)} - C_{(4)} - C_{(3)}$	108,3(7)
$O_{(2)} - C_{(6)} - C_{(7)}$	111,0(8)	$O_{(2)} - C_{(6)} - C_{(10)}$	116,3(7)
$C_{(7)} - C_{(6)} - C_{(10)}$	132,6(8)	$C_{(6)} - C_{(7)} - C_{(8)}$	104,9(7)
$C_{(7)} - C_{(8)} - C_{(9)}$	106,3(8)	$O_{(2)} - C_{(9)} - C_{(8)}$	110,0(6)
$O_{(2)} - C_{(9)} - C_{(11)}$	115,1(6)	$C_{(8)} - C_{(9)} - C_{(11)}$	134,6(8)
$C_{(1)} - C_{(11)} - C_{(9)}$	110.6(6)	$C_{(1)} - C_{(11)} - C_{(12)}$	110,0(6)
$C_{(9)} - C_{(11)} - C_{(12)}$	113,2(6)	$C_{(11)} - C_{(12)} - C_{(13)}$	122,3(6)
$C_{(11)} - C_{(12)} - C_{(17)}$	119,9(6)	$C_{(13)} - C_{(12)} - C_{(17)}$	117,8(5)
$C_{(12)} - C_{(13)} - C_{(14)}$	121,1(6)	$I_{(1)} - C_{(14)} - C_{(13)}$	120,6(5)
$I_{(1)} - C_{(14)} - C_{(15)}$	119,2(4)	$C_{(13)} - C_{(14)} - C_{(15)}$	120,1(6)
$C_{(14)} - C_{(15)} - C_{(16)}$	119,7(6)	$I_{(2)} - C_{(16)} - C_{(15)}$	119,7(6)
$I_{(2)} - C_{(16)} - C_{(17)}$	118,5(5)	$C_{(15)}-C_{(16)}-C_{(17)}$	121,7(6)
$O_{(3)} - C_{(17)} - C_{(12)}$	114,8(5)	$O_{(3)} - C_{(17)} - C_{(16)}$	125,6(6)
$C_{(12)} - C_{(17)} - C_{(16)}$	119,5(6)		

in this case it is necessary to add alcohol.) After the addition the mixture was carefully neutralized with hydrochloric acid solution and diluted with water. The crystals that separated were filtered off, washed with water, dried, and recrystallized from hexane. We obtained 4.4 g (85%) of the product (Id); mp 110-111°C. Found %: C 39.09, H 2.79, I 48.65. $C_{17}H_{14}I_2O_3$. Calculated %: C 39.25, H 2.71, I 48.80.

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