γ-Hydroxypropylation of 2,6-Dialkyl(aryl)phenols with Allyl Alcohol and Its Derivatives

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Abstract—The composition of the products of the reaction of 2,6-disubstituted phenols with allyl alcohol and its derivatives in an alkaline medium was investigated, the conditions for carrying out the reaction with the predominant formation of 4-(3-hydroxypropyl)-2,6-dialkyl(aryl)phenols were found, and its mechanism was suggested. The reaction was examined on an industrial scale. An important result is the practical demonstration of alkaline catalysis performed under homogeneous conditions with participation of phenols, when the used alkaline catalyst is recovered in the process without the formation of waste waters.

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The analysis of the literature data on alkylation of phenols with olefins containing a double bond conjugated with functional substituents COOAlk, CN [1], CONH₂, COAlk, CHO [2], OH [3], reveals the stable interest to this type of reactions. It can be seen, first of all, in the research studies aiming at elaboration of selective methods for the preparation of sterically hindered phenols with a functional group in the aliphatic chain of the para-substituent. Such phenols are used as intermediates in the synthesis of nontoxic additives to polymers produced on the industrial scale [4] as well as for preparation of biologically active compounds [5]. In connection with this, the reaction of 2,6-di-tertbutylphenol (Ia) with allyl alcohol resulting in the formation of 4-(3-hydroxypropyl)-2,6-di-tert-butylphenol **IIIa** (or γ -propanol) [3] required detailed investigation in order to reveal its synthetic potential for preparation of phenols possessing a functional substituent in the γ position of the aliphatic chain of the para-substituent. This investigation is the main goal of the present study.

 $4-\gamma$ -Hydroxypropylphenols are usually prepared by reduction of the corresponding esters of 4-hydroxyphenylpropionic acids [6, 7] or by the reaction of compound **IIIa** with 1,3-propanediol in alkaline medium [8, 9].

The reaction of phenols with allyl alcohol is known to proceed with the formation of ethers, which undergo the Claisen rearrangement (thermally or catalytically) into the o- or p-allylphenols [10]. This method was used for preparation of $4-\gamma$ -hydroxypropylphenols in a considerable amount as described in patent [11], where it was declared that a new reaction of γ -hydroxylpropylation of phenols was discovered by the example of the reaction of 2,6-di-tert-butylphenol with allyl alcohol at 180–230°C in the presence of alkali leading to compound IIIa in 60% yield. This Japanese inventtion was published 20 years later than our works had been done and after we organized the production of compound IIIa in Russia based on this reaction [3, 12]. To improve the yield of γ -hydroxypropylphenols, additional reagents were proposed in [13].

In the first experiments we have found that the reaction of methyl ether of 2,6-di-*tert*-butylphenol with allyl alcohol does not occur either in the absence or in the presence of alkali. Neither in the alkaline medium the reaction of 2,6-di-*tert*-butylphenol with methylallyl ether nor with the allyl alcohol having two methyl groups in the α -position takes place. The reaction of 2,6-di-*tert*-butylphenol with allyl alcohol was realized when the temperature was raised to 140–170°C in the

presence of KOH, but the major products were trisphenol II and bisphenols III, IV–IVa, the products of condensation of 2,6-di-*tert*-butylphenol with compounds formed in the process of oxidative transformations of allyl alcohol. The structure of aliphatic bridges in compounds **II–IV** is indicative of the nature of their precursors, which can be acrolein, propionic aldehyde, and formaldehyde, respectively.



Apart from phenols II, III, GC analysis of the reaction mixture revealed the presence of 23% of compound IIIa. Compound II is poorly soluble in organic solvents and precipitated during the dissolution of the reaction mixture. Its formation is favored when carrying out the reaction in methanol.

High exothermicity of this reaction inconspicuous when performing on a laboratory scale or even in reactors of up to 5 l capacity, is clearly exhibited under the condition of industrial production, in reactors of 1 to 3 m³ capacity. In the heated to 160°C reaction mass, first an inductive period is observed when no visible changes occur (about 1 h), after which for 15 min an exothermic process takes place with vigorous heat evolution leading to the increase of pressure and temperature in the reactor. This technologically dangerous period of the reaction can be tracked in due course and by emergency cooling of the reaction mass to transfer the process to a smooth regime, without increasing the pressure in the reactor above 3 at.

The application of simplex method of mathematical simulation of the experimental conditions with subsequent realization in practice allowed to substantially increase the content of γ -propanol **IIIa** in the reaction mass, according to GC data, from 20 to 90% [12]. The composition of side products also sharply changed. However, the addition of water into the reaction mass, or decrease of the amount of alkali again result in the formation of bis- and trisphenols in the





reaction. The introduction into the reaction mass of anhydrous alcohols, methanol, ethanol or isopropanol, which are the products of transformations of allyl alcohol in the course of the reaction under investigation, has no substantial effect on the composition of the products. This volatile fraction of alcohols is distilled off from the reactor at atmospheric pressure in ca. 3% yield. Ester **VIII** is accumulated in the still, where its content reaches 30%. Apparently, the presence of ester **VIII** known by its high antioxidant activity [14, 15] is manifested in the properties of the still bottoms, which, being added to polymers, provides the required stabilization of the properties of the polyolefin talc-filled compositions for cables [16].

The reaction of 2,6-di-*tert*-butylphenol with large excess of allyl alcohol in an alkaline medium proceeds at the atmospheric pressure at reflux and leads to the predominant formation of compound **IIIa**. However, under industrial conditions this procedure has no technological advantages: the labor comsumption for the recovery of highly toxic allyl alcohol increases and the productivity of the reactor sharply decreases.

In the first stage of γ -oxypropylation of phenols, the initiator of the reaction, sodium 2,6-di-tert-butylphenolate, is prepared, in the presence of which the reaction of 2,6-di-tert-butylphenol with allyl alcohol is performed at 140-170°C. When the reaction is completed the fraction of aliphatic alcohols containing methanol, ethanol, propanol, and allyl alcohol in the molar ratio of 1:1:0.3:3 is distilled off the reactor. Then, in a vacuum the mixture of 2,6-di-tert-butylphenol with 4-alkyl-2,6-di-tert-butylphenols (alkyl = Me, Et, Pr) is distilled in 5-7% yield. Further distillation gives y-propanol IIIa of 95–97% purity. Into the reactor containing the still bottoms, a new portion of allyl alcohol and 2,6-di-tert-butylphenol is charged and the process is repeated. As the catalyst at this and subsequent stages acts the sodium salt of the target product Na-IIIa. Up to 5-6 successive reaction cycles can be performed without additional introducetion of alkali into the reactor and without the formation of waste waters. The yield of product IIIa is ca. 75% [12].

Compound **IIIa** purified by crystallization from toluene forms transparent large cubic crystals with mp $72.0-72.5^{\circ}$ C. In the literature for highly pure product **IIIa** the mp $70-72^{\circ}$ C was given [17].

3-(*tert*-Butyl-4-hydroxy-5-methylphenyl)propanol-1 (**IIIb**) we prepared by heating 2-methyl-6-*tert*-butyl-

phenol (**Ib**) with allyl alcohol in the presence of sodium salt of 2-methyl-6-*tert*-butylphenol at 190–200°C during 2 h. The formed reaction mass contained 72% of compound **XI**. According to patent [13], the content of compound **IIIb** in the reaction mass can be increased to 80% by addition into the original reaction mixture of organomagnesium compounds, sodium metal, and additives of tetraethoxytitanium.

In the reaction of 2,6-xylenol (Ic) with allyl alcohol in an alkaline medium under the conditions of synthesis of compound IIIa, along with product IIIc diphenylmethane Vc is formed in comparable amounts. The vacuum distillation does not allow the isolation of compound IIIc from the reaction mixture. When the temperature of the reaction was lowered to $130-140^{\circ}$ C, the ratio IIIc:Vc became 4:1 permitting the isolation of compound IIIc by simple distillation.

The reaction of 2,6-diphenylphenol (**Id**) with the excess of allyl alcohol and alkali proceeds at 170°C and requires a long time. The obtained reaction mass contains 60% of compound **IIId**, which was earlier obtained from 2,6-diphenylphenol in several steps [18].

As we see, there is no general protocol for one-step preparation of 4-(γ -hydroxypropyl)-2,6-disubstituted phenols. This is because of different acidity of the starting phenols and their different propensity to participate in radical redox processes. When the process of alkylation of phenols is retarded, the side reaction of transformation of alcohols into acids has a negative effect on the composition of the products. We have observed transformation of allyl alcohol into a mixture of acids under the conditions of the studied reaction. They react with alkali to give sodium salts thus retarding the main process of alkylation of phenols, and the formation of water during neutralization may change the course of the reaction.

Based on this experience, we decided to examine the possibility of multiple use of alkali by the example of preparation of methylox **XII** by the reaction of 2,6di-*tert*-butylphenol with methyl acrylate in the presence of potassium salt of 2,6-di-*tert*-butylphenol [19]. However, we succeeded in realization of only one additional operation of preparation of compound **XII**. The reason lies in disappearance of alkalinity in the reactor due to side reaction of alkaline hydrolysis of the esters present in the reaction mass with the formation of acids, which neutralize the alkaline medium.



Ia, $R_1 = R_2 = t$ -Bu; Ib, $R_1 = t$ -Bu, $R_2 = CH_3$; Ic, $R_1 = R_2 = CH_3$; Id, $R_1 = R_2 = Ph$; XVa, $R_3 = R_4 = H$; XVb, $R_3 = H$, $R_4 = H$; XVb, $R_3 = H$; $R_4 = H$; XVb, $R_3 = H$, $R_4 = H$; XVb, $R_4 = H$; XVb, $R_4 = H$; $R_4 = H$; XVb, $R_4 = H$; $R_4 = H$; $R_4 = H$; XVb, $R_4 = H$; R_4 CH₃; **XVc**, R₃ = CH₃, R₄ = H; **XVd**, R₃ = Ph, R₄ = H; **IIIa**, R₁ = R₂ = *t*-Bu, R₃ = R₄ = H; **IIIb**, R₁ = *t*-Bu, R₂ = CH₃, R₃ = $R_4 = H$; IIIc, $R_1 = R_2 = CH_3$, $R_3 = R_4 = H$; IIId, $R_1 = R_2 = Ph$, $R_3 = R_4 = H$; IIIe, $R_1 = R_2 = t$ -Bu, $R_3 = H$, $R_4 = CH_3$; IIIf, $R_1 = R_2 = t$ -Bu, $R_3 = = CH_3$, $R_4 = H$; IIIg, $R_1 = R_2 = t$ -Bu, $R_3 = Ph$, $R_4 = H$; Vb, $R_1 = t$ -Bu, $R_2 = CH_3$; Vc, $R_1 = R_2 = CH_3$.

In the reaction of 2,6-di-tert-butylphenol with cinnamic alcohol XVd along with the major product IIIf from the reaction mass benzyl alcohol XI, 4-benzyl-2,6-ditert-butylphenol (IX) and lactone X were isolated. The formation of alcohol XI and compound IX is indicative

The presence of substituents (CH₃, Ph) in the 1 or 3

positions of allyl alcohol does not prevent its reaction

with 2,6-di-tert-butylphenol and leads to the formation

of the processes of splitting of the double bond of cinnamic alcohol with generation of new agents alkylating compound Ia, whereas lactone X is formed, as we have shown, in the parallel process when cinnamic alcohol and alkali are heated under the reaction conditions.

of the corresponding derivatives of compounds IIId-

IIIf. 1,1-Dimethylallyl alcohol does not enter the

reaction with 2,6-di-*tert*-butylphenol in alkaline medium.



The obtained data are indicative of the fact that the propensity of allyl alcohol XVa and its derivatives XVb-Vd to enter the reaction with 2,6-di-tertbutylphenol is connected with the presence in their molecules of at least one hydrogen atom (a-H) adjacent to the hydroxy group. Its oxidation with the formation of carbonyl compounds is presumably the key stage of γ -hydroxypropylation of phenols.

As to the mechanism of the reaction of 2,6-di-tertbutylphenol with carbonyl compounds in alkaline media, it was shown in [19] that the reaction of phenols with carbonyl compounds proceeded with the preliminary formation of two pecies: a phenoxyl radical and the radical of alcohol. Being applied to the

reaction of methyl acrylate with 2,6-di-tert-butylphenol, this mechanism suggests the formation of 2,6di-tert-butylphenoxyl and the radical of the derivative of allyl alcohol, whose recombination affords product XII. The key role of the alkali metal and its unusual location in the reaction complex are discussed in [20].

Similarly the reaction of 2,6-di-tert-butylphenol with acrolein, which is the product of oxidation of allyl alcohol can be represented. But at the stage of oxidation of the allyl alcohol to acrolein the radical-containing allyl alcohol is formed, which, according to scheme, may be a species responsible for the reaction of 2,6-di-tert-butylphenol with compounds having double bond.



It is known that aldehyde **XIII** can suffer transformations in an alkaline medium to form ester **VIII** [14], which was detected by us among the products of the studied reaction. The main course of the reaction is the reduction of aldehyde **XIII** into γ -propanol **IIIa** by 2,6-di-*tert*-butylphenol or alcohols present in the reaction mass. We have examined the possibility of such reduction and found that heating of ketone **XIV** with allyl alcohol in the presence of alkali results in the formation of phenol **IIIe** in 60% yield.



In the present work we have found two different conditions and two different in nature sets of products of the reaction of 2,6-di-*tert*-butylphenol with allyl alcohol. This may be indicative of the fact that the reaction under consideration may follow different mechanisms depending on the condition of performing the process.

EXPERIMENTAL

Melting points were determined on a Koeffler heating block. ¹H NMR spectra were obtained on a Bruker AV 300 spectrometer (300.13 MHz) from solutions in CCl₄, with TMS and CDCl₃ as internal standards. UV spectra were taken on a Specord UV– VIS spectrometer from 1×10^{-4} molar solutions in ethanol. IR spectra were registered on a Vektor-22 spectrophotometer (Bruker) in KBr or for 1% solutions in CCl₄. High resolution mass spectra were obtained on a Finnigan MAT 8200 instrument, the elemental composition was calculated from spectra with resolution of 10000.

Preparation of bisphenols (IV, VIa, VIIa), trisphenol (II), and γ -propanol (IIIa). The mixture of 20.6 g (0.1 mol) of 2,6-di-tert-butylphenol, 12 g of allyl alcohol, and 5.6 g of granulated KOH was heated in a steel autoclave of 0.1 l capacity at 140°C with stirring for 10 h. After neutralization, 21.3 g of oil was obtained containing, from the GC data, 40% of the starting 2,6-di-tert-butylphenol, 23% of y-propanol IIIa, 23% of 1,1-bis-(3.5-di-tert-butyl-4-hydroxyphenyl)propane (IV), and 13% of tris-1,1,3-(3,5-di-tert-butyl-4-hydroxy-phenyl)propane (II). The oil was dissolved in alcohol and the precipitate was filtered off to obtain 0.9 g of tris-1,1,3-(3,5-di-tert-butyl-4-hydroxyphenyl)propane II as a white powder with mp 210–212°C. ¹H NMR spectrum (CCl₄), δ, ppm: 1.41 s (*t*-Bu, 54 H), 2.14 g (2H, CH₂), 2.39 t (2H, CH₂), 3.62 t (1H, CH), 4.80 s (1H, OH), 4.84 s (2H, OH), 6.80 s (2H, Ar), 6.91 s (4H, Ar). HR-MS: m/z of MI 656.5123; calculated for C₄₅H₆₈O₃, 656.5168.

The filtrate was evaporated and placed into a column with silica gel. Gradient elution with hexaneether gave 4.4 g (17%) of γ -propanol **IIIa** and 3.0 g (6%) of bispropane **IV** with mp 154–156°C. ¹H NMR (CDCl₃), δ , ppm: 0.87 t (3H, CH₃), 1.42 s (36H, *t*-Bu), 1.66–2.12 m (2H, CH₂), 3.57 t (1H, CH), 4.9 s (2H, OH), 7.05 s (4H, Ar). HR–MS: *m/z* of MI 452.3654; calculated for C₃₁H₄₈O₂, 452.3650.

Waste-free preparation of γ -propanol (IIIa). A steel autoclave of 0.2 l capacity equipped with anchor stirrer (v = 348 rpm) was charged with 2,6-di-*tert*butylphenol and NaOH and heated at 130°C for 2 h with stirring and distillation of water in the stream of nitrogen. Then the apparatus was charged with allyl alcohol. The molar ratio Ia:NaOH:XVa was 1:0.29:1.38. The reaction mass was stirred keeping for 2.5 h at 160–180°C, then aliphatic alcohols were γ-HYDROXYPROPYLATION OF 2,6-DIALKYL(ARYL)PHENOLS

distilled off, and the mixture of compound Ia with methyl-, ethyl-, propyl-2,6-di-tert-butylphenols was distilled in a vacuum of 3-5 mm Hg in the temperature range 100–150°C. γ-Propanol (IIIa) is distilled at 170– 180°C (3-4 mm Hg). Then the reactor is charged with the calculated amount of 2,6-di-tert-butylphenol and allyl alcohol and the process is recycled as described above.

To stabilize the total amount of the reaction mass from operation to operation (60-67 wt %) 15% of the still bottoms was removed from the reactor.

After four successive operations, 199.46 g of 99% 2,6-di-tert-butylphenol, 77.8 g of allyl alcohol and 3.52 g of NaOH was used to afford 166.76 g of 99.6% γ-propanol IIIa (yield 69%), 20.88 g of 2,6-di-tertbutylphenol and 90.66 g of still bottoms, which after removal of sodium salts and conversion of phenolates into phenols contained 40% of compound IIIa, 30% of ester VIII, 5% of the mixture of bis- and trisphenols. The residue is oligomeric products of copolymerizetion of olefins with the products of the O- and Calkylation of 2,6-di-tert-butylphenol.

From 10 g of the neutralized still bottoms (pH = 6) 1.5 g of 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propyl-3-(3.5-di-tert-butyl-4-hydroxyphenyl) propionate VIII was isolated by column chromatography on silica gel with gradient elution with the mixture hexane-ether. mp 102–105°C (mp 103–106°C, [14]). ¹H NMR (CCl)₄, δ, ppm: 1.42 s (36H, t-Bu), 1.80 m (2H, -CH₂-), 2.51 t (4H, ArCH₂), 2.72 t (2H, CH₂COO), 4.10 t (2H, OCOCH₂), 4.86 s (1H, OH), 4.88 s (1H, OH), 6.87 s (2H, Ar), 6.92 s (2H, Ar).

This procedure for preparation of γ -propanol IIIa was successfully realized on a pilot plant on Altaikhimprom (Yarovoe) with 13000 times scaling of the charged quantities in a steel reactor of 3 m³ capacity rated at reactions at the pressure up to 5 at. After three successive stages of alkylation of 2,6-di-tert-butylphenol with allyl alcohol 1.3 t of 97% γ-propanol IIIa was obtained. By this and other characteristics the product matches the acting standards.

Preparation of γ-propanol IIIa at atmospheric pressure. A glass flask was charged with 5 g (0.024 mol) of 2,6-di-tert-butylphenol, 6 g (0.15 mol) of NaOH, and 14 g (0.24 mol) of allyl alcohol and heated for 6 h at reflux (114°C). After neutralization of the reaction mass the product was extracted with hexane and the solvent removed to give 6 g of oil containing, from the GC data, 87% of γ -propanol IIIa, 3% of the unreacted

2,6-di-tert-butylphenol, and 10% of high-boiling derivatives of bis- and tris-phenols.

Preparation of 3-(3-tert-butyl-4-hydroxy-5-methylphenyl)propanol-1 (IIIb). The autoclave of 100 ml capacity equipped with stirrer was charged with 30.1 g of 96% 2-methyl-6-tert-butylphenol (Ib) (0.176 mol) and 3.6 g of 99% ground NaOH (0.088 mol), the mixture was heated to 130°C, and water was distilled off the reactor in a vacuum of 25 mm Hg with stirring during 1 h. The reaction mass was cooled to 80°C and 17 ml of allyl alcohol (0.25 mol) was added. The sealed autoclave was heated to 190°C (the temperature was measured inside the reactor) and kept with stirring for 2 h. Then the reactor was cooled to 80°C and the content was neutralized with hydrochloric acid. The cooled reaction mass was extracted with ether, the extract was evaporated to obtain 30 g of viscous oil containing 72% of compound IIIb and 14% of bis(3*tert*-butyl-4-hydroxy-5-methyl-phenyl)methane (**Vb**). The vacuum distillation of the oil at 150-160°C (2-3 mm Hg) gave 14.5 g (37.2%) of 3-(3-tert-butyl-4hydroxy-5-methylphenyl)propanol-1 IIIb with mp 61-63°C (from hexane); mp 61–63°C [13]. UV spectrum (ethanol): λ_{max} 280 nm (log ε 3.32). ¹H NMR (CCl₄), δ , ppm: 1.36 s (18H, t-Bu), 1.60–1.84 m (2H, ArCH₂CH₂), 2.09 s (3H, ArCH₃), 2.52 t (2H, ArCH₂, J 8 Hz), 3.40 t (2H, CH₂OH J 7 Hz), 6.66 d (1H, Ar, J 1 Hz), 6.84 d (1H, Ar, J 1 Hz). The spectrum coincides with that in [21]. HR-MS: m/z of MI 222.1618; calculated for C₁₄H₂₂O₂, 222.1620.

Preparation of 3-(3,5-dimethyl-4-hydroxy-phenyl)propanol-1 (IIIc). The reaction was performed in an inert gas flow. A three-neck flask equipped with stirrer and condenser was charged with 4 g (0.1 mol) of NaOH and 14 ml of allyl alcohol. The mixture was kept for 0.5 h at 90-100°C (bath temperature) until complete dissolution of alkali. Then 6.1 g (0.05 mol) of 2,6-dimethylphenol Ic was added, the temperature of the bath was raised to 135°C, and the stirring was kept for 18 h. After 7 h another portion of allyl alcohol of 7 ml was added to the reactor. After the process the reaction mixture was neutralized, extracted with ether, the extract was washed with water and evaporated to obtain 9.7 g of oil containing, according to GC, 40% of 3-(3,5-dimethyl-4-hydroxyphenyl)propanol-1 (IIIc). 13% of bis-(3,5-dimethyl-4-hydroxyphenyl)methane (Vc) and 43% of 2,6-dimethylphenol (Ic). The oil was distilled in a vacuum to give 2.7 g of the oil with bp 130-135°C (1 mm Hg), which crystallized upon standing. mp of compound IIIc 65-68°C (from hexane

with addition of alcohol) (68–69°C [23]). Found: $C_{11}H_{16}O_2$, *m/z* 180.1150 (mass-spectrometrically). Calculated: *m/z* 180.1150.

4-(3-Hvdroxypropyl)-2,6-diphenylphenol (IIId). A steel autoclave of 20 ml capacity was charged with 4.92 g (0.02 mol) of 2,6-diphenylphenol (Id), 6.8 ml (0.1 mol) of allyl alcohol, and 0.8 g (0.02 mol) of ground NaOH. The mixture was heated on a rocking device at 170°C for 24 h. The cooled reaction mixture was dissolved in ether, neutralized by hydrochloric acid to pH 5, the organic layer was washed with water and the solvent was removed to give 5.3 g of oil containing, according to GC, 58% of compound IIId. The product was purified by column chromatography on silica gel, eluent benzene with ethyl acetate, to afford 2.2 g of oil crystallized upon standing. The solid mass was washed with hexane, mp 78-80°C (82°C from benzene–hexane [18]). UV spectrum (ethanol), λ , nm (log ɛ): 205 (4.31), 239 (3.70), 303 (3.65). IR spectrum (CCl₄), v, cm⁻¹: 3640, 3560 (OH). ¹H NMR $(CCl_4 + C_6D_6)$, δ , ppm: 1.7–1.9 m (2H, CH₂CH₂CH₂), 2.60 t (2H, ArCH₂, J 7.5 Hz), 3.51 t (2H, J 6.0 Hz), 6.94 s (2H, ArH), 7.1-7.5 m (10H, C₆H₅-Ar).

Preparation of 4-(3,5-di-tert-butyl-4-hydroxyphenyl)butanol-2 (IIIe). a. A steel autoclave of 50 ml capacity was charged with 6.92 g (0.034 mol) of 2,6di-*tert*-butylphenol, 4.85 g (0.067 mol) of α methylallyl alcohol XVb and 1.36 g (0.034 mol) of NaOH. The reaction mixture was stirred by rotating the autoclave for 3.5 h at 140C°C, cooled, and treated as in the previous experiment. 7 g of oil was obtained containing, from the GC data, 45% of 2,6-di-tertbutylphenol and 51% of compound IIId, which was distilled in vacuum collecting 2.7 g of fraction with bp 152–155°C (1–2 mm Hg). After crystallization from hexane, 2.09 g (22%) of compound (IIId) with mp 64– 65°C was obtained. UV spectrum (EtOH): λ_{max} 276 nm $(\log \varepsilon 3.22)$. ¹H NMR (CCl₄), δ , ppm: 1.16 d (3H, CH₃), J 6.5 Hz), 1.38 s (18H, t-Bu), 1.62–1.90 m (2H, ArCH₂CH₂), 2.50 t (2H, ArCH₂, J 8 Hz), 3.5-3.9 m (1H, CHOH), 4.86 s (1H, ArOH), 6.85 s (2H, Ar). HR–MS: m/z of MI 278.2250; calculated for C₁₈H₃₀O₂, m/z 278.2250.

b. A steel autoclave of 50 ml capacity was charged with 8.28 g (0.03 mol) 4-(3,5-di-*tert*-butyl-4-hydroxy-phenyl)butanone-2 (**XIV**), 7.0 ml (0.1 mol) of allyl alcohol and 1.2 g (0.03 mol) NaOH and heated at 140°C for 3 h. After neutralization of the reaction mass 13.3 g of oil was obtained, from which 5 g (0.18 mol, 60%) of

compound **IIIe** was obtained by column chromatography on silica gel (eluent hexane–ether).

Preparation of 3-phenyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)propanol-1 (IIIg). A steel autoclave of 0.1 l capacity was charged with 20.6 g (0.1 mol) 2,6di-tert-butylphenol. 40.2 g (0.3 mol) of cinnamic alcohol XVd, and 4.0 g (0.3 mol) of NaOH. The reaction mass was stirred by rotating the autoclave for 5 h at 140°C, cooled, and treated as in method a. 50.5 g of oil was obtained containing, from the GC data, 24.5% of compound IIIg, 3% of 4-benzyl-2,6-di-tertbutylphenol IX, and 5% of compound XI. After vacuum distillation, 6.2 g of oil was obtained with bp 60–75°C (1 mm Hg), which contained 60% of benzyl alcohol XI (from GC analysis). This compound was isolated by column chromatography on silica gel, eluent hexane-ether 1:1 and identified by comparing its spectral characteristics with those of the authentic sample. 11.2 g of fraction (oil) with bp 140–170°C (1 mm Hg) was placed in the column with silica gel and eluted with the mixture hexane-ether 6:1 to obtain 4-benzyl-2,6-di-tert-butylphenol (IX), mp 58–59°C; 61°C [22]. UV spectrum (EtOH): λ_{max} 265 nm (log ϵ 3.21), 271 nm (log ε 3.23), 278 nm (log ε 3.24). ¹H NMR (CCl₄), δ, ppm: 1.38 s (18H, *t*-Bu), 3.85 s (2H, CH₂), 4.85 s (1H, ArOH), 6.87 s (2H, Ar), 6.97-7.30 m (5H, Ph).

By further elution of the column with the mixture hexane–ether 1:1 6.40 g (18%) of 3-phenyl-3-(3,5-di*tert*-butyl-4-hydroxyphenyl)propanol-1 (**HIg**) was isolated, mp 107–110°C (from hexane). UV spectrum (EtOH): λ_{max} 232 nm (log ε 3.85), 266 nm (log ε 3.19), 271 nm (log ε 3.19). ¹H NMR (CCl₄, δ): 1.36 s (18H, *t*-Bu), 1.84–2.40 m (2H, CH₂CH₂OH), 3.0 s (1H, CH₂OH), 3.45 t (2H, ArCH₂, *J* 7 Hz), 3.95 t (2H, CH₂OH, *J* 8 Hz), 4.9 s (1H, ArOH), 6.9 s (2H, Ar), 6.95–7.30 m (5H, Ph). HR–MS: *m/z* of MI 340.2424; calculated for C₂₃H₃₂O₂, *m/z* 340.2402.

Washing of the column with ether gave (4S,5R)-5benzyl-tetrahydro-4-phenylpyran-2-one (**X**) with mp 94.0–95.5°C (from ethanol). ¹H NMR (CCl₄ + C₆D₆), δ , ppm: 2.26 m (1H, H-4), 2.2–2.4 m (1H, CH⁴Ph), 2.49 m (1H, H-3_{ax}), 2.65 m (1H, H-3_{eq}), 2.5–2.7 m (1H, CH^BPh), 2.77 m (1H, H-5), 2.89 m (1H, H-6_{ax}), 4.16 m (1H, H-6_{eq}), 6.9–7.35 m (10H, Ar). HR–MS: *m/z* of MI 266.1306; calculated for C₁₈H₁₈O₂, *m/z* 266.1306. The assignment of all signals was done with use of europium shift reagent which was twice introduced into the NMR tube with the solution of **X** and the ¹H NMR spectrum was taken. Then the downfield shift of each proton in compound X was plotted as a function of the added reagent and the H–H coupling constants were calculated that allowed to assign the compound the structure given in the scheme.

Reaction of cinnamic alcohol with alkali. A steel rotating autoclave of 50 ml capacity was charged with 10 g of cinnamic alcohol **XVd** and 1.0 g of NaOH and kept rotating for 5 h at 140°C in the helium atmosphere. 7.85 g of the mixture containing, from the GC analysis, 37% of benzyl alcohol **XI**, 23% of cinnamic alcohol **XVd** and 23% of compound **X** was obtained.

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