was formed. After cooling to room temperature, the solid was removed by filtration and recrystallized from ethyl acetate, giving *p*-nitro-ω-styryl methyl sulfone (*ca.* 90%), m.p. 192.5–193.5°.

Anal. Calcd. for $C_9H_9NO_4S$: C, 47.58; H, 3.96; N, 6.17; S, 14.10. Found: C, 47.42; H, 4.00; N, 6.35; S, 14.00.

Preparation of 1-Bromo-2-phenylethyl *p*-Tolyl Sulfone.—Ethylmagnesium bromide was prepared under nitrogen from magnesium (5.0 g., 0.208 g.-atom), ethyl bromide (21.8 g., 0.2 mole), and anhydrous ether (40 ml.). To this solution was added 2-phenylethyl *p*-tolyl sulfone (45.0 g., 0.173 mole) in dry benzene (150 ml.). After the evolution of ethane had ceased, an additional 100 ml. of dry benzene was added. The stirred mixture was refluxed for 3 min., then cooled in an ice bath. Bromine (24 g., 0.15 mole) in 50 ml. of dry benzene was added. The ice bath was removed, and the mixture was stirred at room temperature for 2 hr., then poured into water (*ca.* 300 ml.) Excess bromine was removed by addition of a solution of sodium bisulfite. Magnesium particles were removed by filtration. The benzene layer was separated and evaporated to dryness. Recrystallization of the solid residue from ethanol produced 36 g. of 1-bromo-2-phenylethyl *p*-tolyl sulfone (70%), m.p. 121–122°. The n.m.r. spectrum of this compound was identical with that of 1-chloro-2-phenylethyl *p*-tolyl sulfone (I) obtained by the Meerwein procedure.

Anal. Calcd. for $C_{15}H_{15}BrO_2S$: C, 53.10; H, 4.42; Br, 23.60; S, 9.44; mol. wt., 339. Found: C, 53.36; H, 4.41; Br, 23.72; S, 9.24; mol. wt., 339.

Independent Preparation of 1-Chloro-2-phenylethyl *p*-Tolyl Sulfone (I).—A solution of *n*-propylmagnesium chloride was prepared under nitrogen from magnesium (4.8 g., 0.2 g.-atom), *n*-propyl chloride (17.7 g., 0.228 mole), and anhydrous ether (40 ml.). To this was added 2-phenylethyl *p*-tolyl sulfone (45 g., 0.173 mole) in dry benzene (150 ml.). After the evolution of propane had ceased, an additional 100 ml. of dry benzene was added and the stirred mixture was refluxed for 5 min., then cooled in an ice bath. Excess chlorine was bubbled into the cold, stirred solution (for about 20 min. at a high rate). The solution was stirred for 2 hr., then poured into water (*ca.* 200 ml.). The benzene layer was washed with water to remove excess chlorine and evaporated to 100 ml. After cooling, the first crop of solid (4.1 g.) was collected (m.p. 177–179°, after recrystallization from absolute ethanol). The n.m.r. spectrum and molecular weight of this product indicate that it is 1,1-dichloro-2-phenylethyl *p*-tolyl sulfone.

Anal. Calcd. for $C_{15}H_{14}Cl_2O_2S$: mol. wt., 329. Found: mol. wt., 329.

Evaporation of the benzene filtrates to 50 ml. and filtration of the precipitate produced a second crop of solid (18.05 g.), m.p. 65–100°. A third crop of solid (10.3 g.) was obtained by evaporating the benzene filtrates to dryness and recrystallizing the residue from absolute ethanol. Chromatography of 3.8 g. of the third crop on an alumina column, eluting with benzene–pentane (1:1, 800 ml.), produced 1.08 g. of 1-chloro-2-phenylethyl *p*-tolyl sulfone, m.p. 79–82° after recrystallization from ethanol. This compound did not depress the melting point of 1-chloro-2-phenylethyl *p*-tolyl sulfone obtained by the Meerwein procedure, and the infrared and n.m.r. spectra of the two samples were identical.

Anal. Calcd. for $C_{15}H_{15}ClO_2S$: C, 61.12; H, 5.09; Cl, 12.05; S, 10.87; mol. wt., 294.5. Found: C, 61.31; H, 5.14; Cl, 11.88; S, 10.67; mol. wt., 290.

Acknowledgment.—This work was supported by the U. S. Army Research Office under Grant No. DA-ARO(D)-31-124-G146 and by Public Health Service Research Grant No. CA-04536-07 from the National Cancer Institute.

Out-of-Ring Claisen Rearrangements[1]

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The objective was to investigate Claisen rearrangements of allyl groups to carbons that are located outside the parent phenol ring. Pyrolysis of the allyl ether (**7**) of 2,6-dimethyl-4-propenylphenol (**6**) in ethanol at 200° followed by catalytic hydrogenation gave 2,6-dimethyl-4-propylphenol (**9**, 8.5%) and 2,6-dimethyl-4-(2-methylpentyl)phenol (**12**, 32%). The formation of **12** from **7** is explicable by a sequence of *three* consecutive cyclic transition states, the last of which shifts the allyl group out-of-ring to the β-carbon of the *para* side chain. To examine if the olefinic unit acting as the allyl acceptor in out-of-ring rearrangements could itself be part of a second phenyl ring, the allyl ethers of 3,5-dimethyl-4-hydroxybiphenyl (**13**) and 2-hydroxy-3,5-dimethylbiphenyl (**15**) and the bisallyl ether of 3,5,3′,5′-tetramethyl-4,4′-dihydroxybiphenyl (**17**) were prepared. On pyrolysis these allyl ethers disproportionated to the corresponding parent phenols; consequently, the phenyl ring acted as a blocking group and not as an allyl acceptor. A crystalline 1:1 adduct was obtained when the allyl ether of **13** was heated with maleic anhydride.

The intramolecular, thermal rearrangement of allyl phenyl ethers to *o*-allylphenols (Claisen rearrangement) involves cyclic, six-membered transition states.[3] When the *ortho* positions of the aromatic ring are suitably blocked the allyl group can migrate to the *para* carbon in two successive cyclic stages, each accompanied by a "reversal"[4] of the allyl group.[5,6]

In 1926 Claisen and Tietze reported a variant in which the migrating allyl group eventually became attached to the central carbon of an *o*-propenyl side chain (*e.g.*, **1a** → **2a**).[7] Recent studies on this "out-of-ring" Claisen rearrangement by Lauer and Wujciak showed that pyrolysis of the γ-substituted allyl ether **1b** gave **2b** in 23% yield (along with some of the cleavage product, 2,4-dimethyl-6-propenylphenol). By analogy with the *para* Claisen rearrangement, they formulated this out-of-ring migration as a two-cycle

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[1] Taken from the Ph.D. Dissertation of B. R. Aaronoff, The Johns Hopkins University, 1962. A preliminary account of the work has been published [A. Nickon and B. R. Aaronoff, *J. Org. Chem.*, **27**, 3379 (1962)] and was presented at the 142nd Meeting of the American Chemical Society, Atlantic City, N. J., Sept., 1962.

[2] Fellow of the Alfred P. Sloan Foundation.

[3] D. S. Tarbell, *Org. Reactions*, **2**, 1 (1944).

[4] An allyl unit attached initially by its α-carbon is said to be "reversed" (or "inverted") when the final attachment is through its (original) γ-carbon. The double bond undergoes an allylic shift in the process.

[5] (a) C. D. Hurd and M. A. Pollack, *J. Org. Chem.*, **3**, 550 (1938); (b) S. J. Rhoads, R. Raulins, and R. D. Reynolds, *J. Am. Chem. Soc.*, **76**, 3456 (1954); (c) J. P. Ryan and P. R. O'Connor, *ibid.*, **74**, 5866 (1952); (d) H. Schmid and K. Schmid, *Helv. Chim. Acta*, **36**, 489 (1953); (e) H. Conroy and R. A. Firestone, *J. Am. Chem. Soc.*, **78**, 2290 (1956); (f) D. Y. Curtin and R. J. Crawford, *ibid.*, **79**, 3156 (1957); (g) E. N. Marvell and R. Teranishi, *ibid.*, **76**, 6165 (1954); (h) D. Y. Curtin and H. W. Johnson, *ibid.*, **76**, 2276 (1954); **78**, 2611 (1956); (i) K. Schmid, W. Haegele, and H. Schmid, *Experientia*, **9**, 414 (1953); (j) W. Haegele and H. Schmid, *Helv. Chim. Acta*, **41**, 657 (1958); (k) K. Schmid, W. Haegele, and H. Schmid, *ibid.*, **37**, 1080 (1954).

[6] For a recent review and leading references, see S. J. Rhoads, "Molecular Rearrangements," P. de Mayo, Ed., Interscience Publishers, Inc., New York, N. Y., 1963, part 1, p. 655.

[7] L. Claisen and E. Tietze, *Ann.*, **449**, 89 (1926).

CHART I

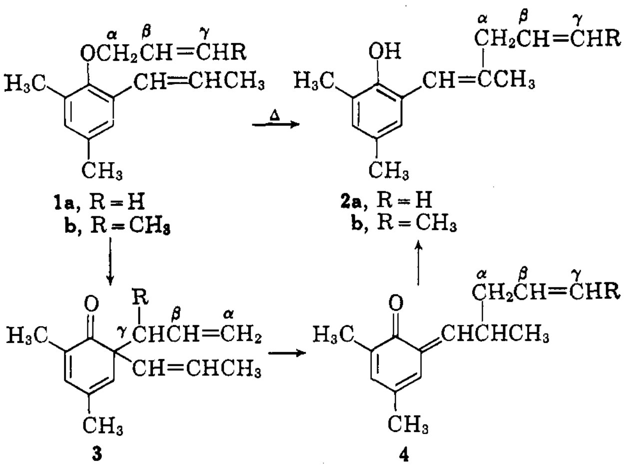
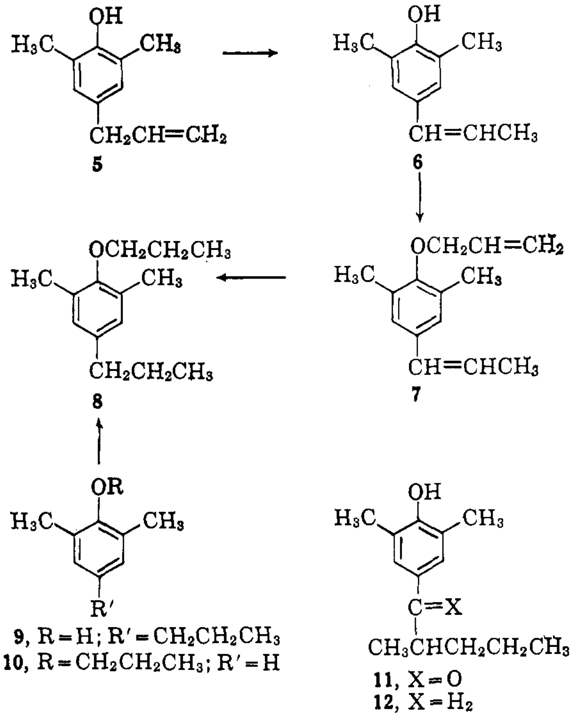


CHART II



process *via* the expected intermediates **3** and **4**.[8] Schmid, Fahrini, and Schmid[9] used C^{14}-labeling to establish the intramolecularity and the skeletal changes in the out-of-ring rearrangements. They observed that **1a**, which was labeled with C^{14} at the allyl γ-carbon, gave **2a** in 42–44% yield when heated at 170° for 20 hr. in diethylaniline. The product had most of its radioactivity (84%) at the γ-carbon (see **2a**), in accord with a two-cycle mechanism for the principal pathway.[10] (See Chart I.)

The ability of an allyl group to shift in two successive cycles either to a *para* position of an aromatic ring or out-of-ring to an *o*-propenyl side chain led us to consider the feasibility of multistage rearrangements in which the allyl group traverses even greater distances if the intermediates possess the proper structural features. Our first aim was to attempt the rearrangement of an allyl group to a terminus that could be reached *via* three consecutive Claisen cycles, and the substrate chosen was allyl 2,6-dimethyl-4-propenylphenyl ether (**7**). A second objective was to determine if the olefinic unit serving as the allyl acceptor in out-of-ring rearrangements could itself be part of a second phenyl ring. In this phase of the work we studied the allyl ethers of 3,5-dimethyl-4-hydroxybiphenyl (**13**) and 2-hydroxy-3,5-dimethylbiphenyl (**15**) and the bis-allyl ether of 3,5,3',5'-tetramethyl-4,4'-dihydroxybiphenyl (**17**).

Preparation of Phenols and Ethers.—Chart II summarizes the synthesis of **7** and of other compounds relevant to the study of its pyrolysis. Thermal rearrangement of allyl 2,6-xylyl ether by the method of Tarbell and Kincaid[11] gave 2,6-dimethyl-4-allylphenol (**5**), which was isomerized to 2,6-dimethyl-4-propenylphenol (**6**) by treatment with hot methanolic potassium hydroxide. Phenol **6** (m.p. 72–76°) showed strong infrared absorption at 958 $cm.^{-1}$ characteristic of a *trans*-disubstituted olefin and a weak band at 721 $cm.^{-1}$. The latter band and the lack of a sharp melting point may indicate the presence of some *cis* isomer. Other infrared bands of **6** are compatible with its assigned structure and the ultraviolet absorption compares well with those of other *p*-vinylic phenols.[12] Treatment of **6** with allyl bromide and potassium carbonate gave **7** as a liquid whose infrared spectrum was consistent with the presence of a monosubstituted olefin (990 and 920 $cm.^{-1}$) and a *trans*-disubstituted olefin (960 $cm.^{-1}$). When hydrogenated in ethanol (platinum catalyst), **7** absorbed 2.08 molar equiv. of hydrogen and gave the corresponding dipropyl compound **8** as a colorless liquid. Because the infrared spectrum of **8** showed strong absorption at 965 $cm.^{-1}$ (a region usually characteristic of a *trans*-disubstituted olefin[13]), we also synthesized it by direct O-propylation of 2,6-dimethyl-4-propylphenol (**9**) with *n*-propyl iodide in alkaline medium. The infrared spectra of **8** from both routes were virtually identical. As a further check we prepared propyl 2,6-xylyl ether (**10**) by catalytic hydrogenation (platinum in ethanol) of allyl 2,6-xylyl ether as well as by direct O-propylation of 2,6-xylenol. The infrared spectrum of the liquid ether **10** also showed strong absorption at 965 $cm.^{-1}$. Consequently, this absorption in **8** is not due to an olefin impurity but evidently is associated with the 2,6-dimethyl-1-propyloxyaryl system.

Phenol **12** was synthesized as follows. Friedel–Crafts acylation of 2,6-xylenol with 2-methylpentanoyl chloride gave 2,6-dimethyl-4-(2-methylpentanoyl)phenol (**11**) as a solid whose carbonyl stretching band appeared at 1645 $cm.^{-1}$ (potassium bromide). High pressure hydrogenation of **11** with copper chromite in ethanol produced 2,6-dimethyl-4-(2-methylpentyl)-phenol (**12**) as a liquid, which was characterized as such and also by preparation of a crystalline α-naphthylurethan.

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[8] W. M. Lauer and D. W. Wujciak, *J. Am. Chem. Soc.*, **78**, 5601 (1956).

[9] K. Schmid, P. Fahrini, and H. Schmid, *Helv. Chim. Acta*, **39**, 708 (1956).

[10] The remainder of the radioactivity (16%) was at the α-carbon (see **2a**). Various minor competing pathways that could account for the small proportion of "reversal" of this type have been suggested [ref. 9 and also P. Fahrini and H. Schmid, *ibid.*, **42**, 1102 (1959); E. Zbiral, F. Wessely, and J. Jorg, *Monatsh.*, **92**, 654 (1961)].

[11] D. S. Tarbell and J. F. Kincaid, *J. Am. Chem. Soc.*, **62**, 728 (1940).

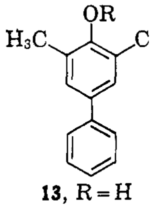
[12] A. R. Bader, *ibid.*, **78**, 1709 (1956). Our phenol **6** became colored and tacky on exposure to air, and Bader noted similar instability of his *p*-vinylic phenols.

[13] L. J. Bellamy, "The Infrared Spectra of Complex Molecules," 2nd Ed., John Wiley and Sons, Inc., New York, N. Y., 1958, p. 45.

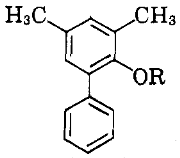
Two routes were used to prepare 3,5-dimethyl-4-hydroxybiphenyl (**13**).[14] In the first, diazotized 2,6-dimethyl-4-aminoanisole was coupled with benzene (Gomberg reaction[15]) to give 3,5-dimethyl-4-methoxybiphenyl. Demethylation with hydriodic acid liberated the corresponding phenol **13**, which was characterized and also converted to its 3,5-dinitrobenzoate and α-naphthylurethan. Our second route to **13** was made possible by the finding of Wolf and Kharasch that biphenyls are obtainable by photolysis of aryl iodides in aromatic solvents.[16] Applying their technique, we made **13** directly by irradiating a benzene solution of 2,6-dimethyl-4-iodophenol with a mercury lamp. The corresponding allyl ether **14** was obtained from **13** by treatment with allyl bromide.

Similar ultraviolet irradiation of 2,4-dimethyl-6-iodophenol in benzene provided 2-hydroxy-3,5-dimethylbiphenyl (**15**) as a liquid, from which were obtained crystalline phenylurethan and α-naphthylurethan derivatives. The ether **16** was obtained by conventional allylation.

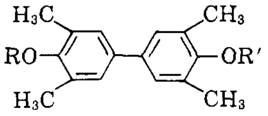
The accessibility of 3,5,3′,5′-tetramethyl-4,4′-dihydroxybiphenyl (**17**) in two steps from 2,6-xylenol[17,18] prompted us to include this difunctional system in our studies. By appropriate treatment with allyl bromide, **17** was converted separately into the monoallyl ether **18** and to the bisallyl ether **19**.



13, R = H
14, R = $CH_2CH{=}CH_2$



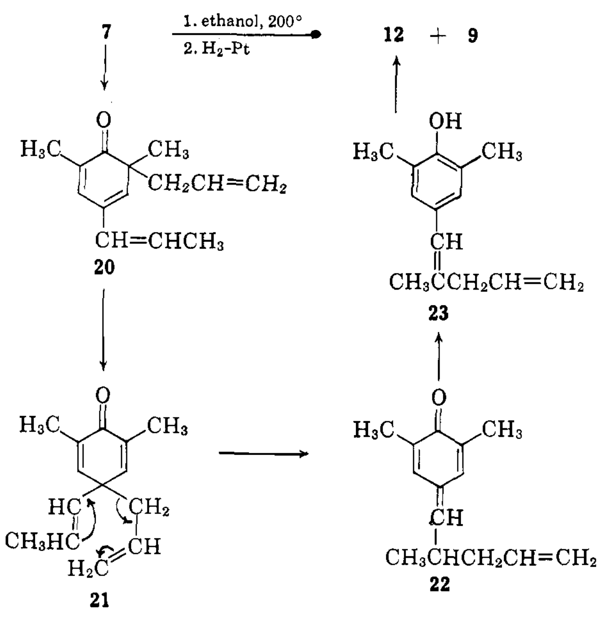
15, R = H
16, R = $CH_2CH{=}CH_2$



17, R = R′ = H
18, R = H; R′ = $CH_2CH{=}CH_2$
19, R = R′ = $CH_2CH{=}CH_2$

Pyrolyses of Allyl Ethers.—The allyl ether **7** in 95% ethanol was heated at 200° in a sealed tube for 8 hr. and the solution was directly hydrogenated (with platinum) to obviate handling of the air-sensitive unsaturated phenols.[12] Chromatography of the hydrogenated product on alumina gave initial fractions rich in 2,6-dimethyl-4-(2-methylpentyl)phenol (**12**), identified by its retention time on gas chromatography and by its infrared spectrum. Some unidentified material with carbonyl absorption at 1706 $cm.^{-1}$ was a contaminant. Later fractions contained **12** along with progressively increasing proportions of 2,6-dimethyl-4-propylphenol (**9**). Analysis of individual and pooled fractions by gas chromatography and by infrared spectroscopy showed that the total product from column chromatography (41% yield by weight) contained **12** and **9** in the ratio 79:21, corresponding to actual molar yields of about 32 and 8.5%, respectively, along with an estimated 2% (by weight) of the unidentified carbonyl material. Phenol **12** was isolated from pooled fractions by preparative gas chromatography and was converted to an α-naphthylurethan, which was identical (melting point, mixture melting point, and infrared spectrum) with the authentic sample. (See Chart III.)

CHART III



In view of the established intramolecularity and cyclic character of normal Claisen rearrangements and (where studied) of out-of-ring rearrangements, the expected principal pathway in the conversion of **7** → **12** would involve *three* consecutive cycles. These bring about a shift to an *ortho* position (intermediate **20**) then to the *para* position (intermediate **21**) and ultimately out-of-ring to the propenyl chain (intermediate **22**).[19] Tautomerization of **22** leads to the unsaturated phenol **23**, the hydrogenation of which produces **12**. The concomitant formation of the parent phenol **6** (implied by the identification of its hydrogenated analog **9**) was not unexpected because loss of allyl groups *via* thermal splitting is one of the side reactions known to accompany the out-of-ring rearrangements.[8,9]

Conceivably, unsaturated groups other than propenyl could serve as allyl acceptors in out-of-ring migrations. A phenyl group as a potential receiver was of particular interest because of the possibility of effecting allyl transfer from one phenyl ring to another (visualize, for example, the conversion of **14** to **26** *via* intermediates **24** and **25**). Experimentally we observed that treatment of **14** in decalin at 250° for 8 hr. followed by elution chromatography gave the parent phenol **13** in 75% yield and no indication (by infrared) of C-allylated phenolic products. Milder pyrolysis (neat at 200° for 3 hr.) also led to the parent phenol **13** (14%) together with 60% of the starting ether **14**. Evidently,

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[14] This phenol has since been obtained by still a different route [T. Kunitake and C. C. Price, *J. Am. Chem. Soc.*, **85**, 761 (1963)]. Their sample and ours agree in melting point, and the infrared spectra were shown to be identical. We are grateful to Professor C. C. Price for making this comparison.

[15] W. E. Bachmann and R. A. Hoffman, *Org. Reactions*, **2**, 224 (1944).

[16] W. Wolf and N. Kharasch, *J. Org. Chem.*, **26**, 283 (1961).

[17] C. Walling and R. Hodgdon, *J. Am. Chem. Soc.*, **80**, 228 (1958).

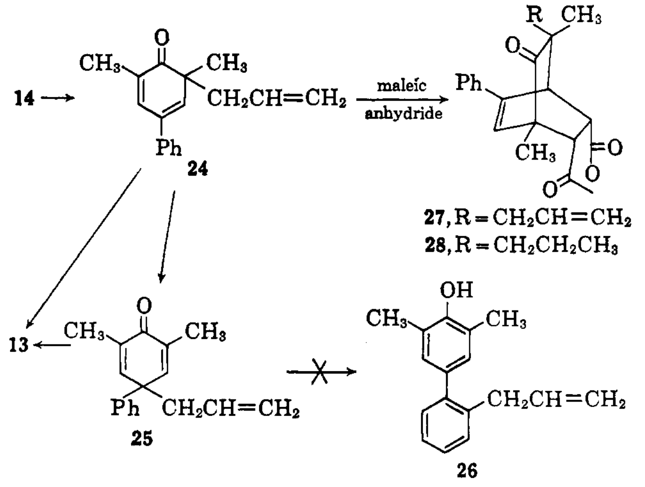
[18] S. L. Cosgrove and W. A. Waters, *J. Chem. Soc.*, **388** (1951).

[19] A mechanism *via* three six-membered cycles predicts net reversal of the allyl group, although the intervention of minor secondary pathways might not make it the exclusive result (*cf.* the findings of Schmid, *et al.*, ref. 9). An allyl unit made unsymmetrical by substitution or isotopic labeling would be required to establish this point.

the expected dienone intermediates **24** and **25** (Ph = phenyl) prefer to split off the allyl unit rather than to continue the sequence that would lead to **26**.

To demonstrate that the allyl group migrates at least to an *ortho* position (see **24**) we pyrolyzed **14** in the presence of maleic anhydride and obtained in good yield a 1:1 adduct, assigned structure **27** on the basis of its physical constants and by analogy with a similar Diels–Alder addition reported by Conroy and Firestone.[5e] Our adduct **27** has ultraviolet maxima in ethanol at 260 (ϵ 13,900) and 305 mμ (ϵ 2400), assigned to the styryl[20] and ketonic chromophores; and infrared absorption at 1852, 1773 (cyclic anhydride), 1709 (ketone), and 1634 cm.$^{-1}$ (terminal olefin) in addition to various C–H bending bands expected of the olefinic and aromatic units. The stereochemistry of **27** was not established but is presumed by analogy.[5e] When the adduct was hydrogenated in ethyl acetate with palladium–charcoal, it formed a dihydro derivative (**28**) whose ultraviolet and infrared spectra indicated that the double bond of the allyl chain had been saturated. (See Chart IV.)

CHART IV



The thermal behavior of **16** paralleled that of **14**. When **16** was heated either in decalin (250° for 8 hr.) or without solvent but in the presence of sodium carbonate[21] (220° for 5 hr.), the parent phenol **15** was isolated in 76–77% yield. In neither case did infrared inspection reveal any C-allylated products in the phenolic fractions from the chromatographic work-up.

Because 4,4′-dihydroxybiphenyls are easily autoxidized to diphenoquinones, we conducted the pyrolysis of **19** (250° for 8 hr.) in a solution of acetic anhydride and pyridine to protect derived hydroxyl groups by acetylation.[22] After chromatography on alumina, we isolated in about 59% yield the diacetate of the parent phenol **17**, and identified it by melting point and infrared comparisons with an authentic sample.[18,23] No infrared absorption characteristic of the allyl function was detected in any of the chromatography fractions.

From the findings with the allyl biphenyl ethers **14**, **16**, and **19** we conclude that a phenyl ring functions preferentially as a blocking group rather than as an allyl acceptor. The results imply that the dienone intermediates prefer fragmentation rather than cyclic rearrangement that must disrupt a second phenyl ring. Our findings do not preclude the possibility of successful out-of-ring rearrangements to ring systems with less aromatic character than phenyl or with other favorable structural features.

Experimental[24]

Reagents.—Column chromatography was carried out on Fisher Scientific Co. adsorption alumina A-540 (80–200 mesh) or on Alcoa activated alumina F-20 (80–200 mesh). Petroleum ether refers to that fraction boiling between 40 and 60°, hexane between 60 and 70°, light petroleum between 66 and 75°, and ligroin between 100 and 115°. Decalin was purified as reported.[25] Eastman practical grade 2,6-xylenol was sublimed (m.p. 47–49°) and 2,4-xylenol (Terra Chemicals, Inc.) was distilled (b.p. 55–60° at 0.1 mm.) before use. Eastman Grade allyl bromide was distilled before use, b.p. 69–71° Phenylurethan and α-naphthylurethan derivatives were prepared in conventional manner.[26a]

2,6-Dimethyl-4-allylphenol (**5**).—The allylation[27] of 2,6-xylenol and rearrangement of the ether[28] were carried out as reported. The product had b.p. 86 88° (1 mm.), n^{18}D 1.5395; lit.[11] b.p. 90.5–91.4° (2 mm.), n^{25}D 1.5370.

The α-naphthylurethan of **5**, after crystallization from ligroin, had m.p. 163–164.5°.

Anal. Calcd. for $C_{22}H_{21}N_2O$ (331.4): C, 79.73; H, 6.39. Found: C, 79.82; H, 6.20.

2,6-Dimethyl-4-propenylphenol (**6**).—A general procedure by Claisen and Tietze[7] was modified as follows. A mixture of **5** (10 g.) and 35 ml. of a saturated solution of potassium hydroxide in methanol was distilled until 25 ml. had come over, and the flask temperature had reached 133°. The mixture was stirred and refluxed 12 hr. at that temperature under nitrogen. The cooled solution was dissolved in water, neutralized with dilute hydrochloric acid, and extracted with ether. The extract was washed with dilute sodium bicarbonate solution and with water and then dried over magnesium sulfate. Removal of the ether left an orange solid, which did not crystallize from the usual solvents. Vacuum distillation with a short-path condenser gave 3.9 g. (39%) of **6** as colorless crystals, m.p. 72–76°; ν^{CS_2} 3620, 958, and 721 cm.$^{-1}$ (weak); no bands characteristic of the allyl group (about 990 and 930) were present. In chloroform, the conjugated olefin absorption at 1595 was evident. The ultraviolet maxima were $\lambda^{95\%\ EtOH}$ 262 mμ (ϵ 16,600) and 294 sh (2700); λ_{min} 230 mμ (ϵ 4400).[12] On air exposure for several days the crystalline material turned yellow and became tacky.

Anal. Calcd. for $C_{11}H_{14}O$ (162.2): C, 81.44; H, 8.70. Found: C, 81.56; H, 8.64.

The α-naphthylurethan of **6** had m.p. 192.5–195° dec. (vac.) after several crystallizations from ligroin.

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[20] D. C. Kleinfelter and P. von R. Schleyer [*J. Org. Chem.*, **26**, 3740 (1961)] observed λ 262.5 mμ (ϵ 10,700) for 2-phenylnorbornene in ethanol.

[21] Sodium carbonate is reported to catalyze the rearrangement of γ,γ-dimethylallyl phenyl ether, which evidently does not rearrange when heated alone or with neutral salts. L. Claisen, *J. prakt. Chem.*, [2]**105**, 65 (1922); A. W. Baker and A. T. Shulgin, *J. Am. Chem. Soc.*, **81**, 4524 (1959).

[22] L. F. Fieser and W. C. Lothrop [*ibid.*, **58**, 749 (1936)] used a similar trapping technique for the rearrangement of a diallyloxyanthracene.

[23] K. von Auwers and T. Markovitz, *Chem. Ber.*, **38**, 226 (1905); *ibid.*, **41**, 2332 (1908); *ibid.*, **57**, 1270 (1924).

[24] Melting points were taken in Pyrex capillaries with a Hershberg apparatus, are corrected and rounded to the nearest 0.5°. Boiling points are uncorrected. Refractive indices were determined on a Bausch and Lomb Co., Abbe-type refractometer and densities were obtained with a Fisher-Davidson gravitometer. Infrared spectra were recorded on a Perkin-Elmer Model 21 spectrophotometer equipped with sodium chloride optics. Ultraviolet spectra were recorded on a Beckman DK-2 recording spectrophotometer. Routine gas chromatography was carried out with a 2-ft. stainless steel column. The stationary phase was 20 wt. % of Dow-Corning High-Vac silicone grease on acid-washed Chromosorb. The carrier gas was helium at about 10 p.s.i.g. (*ca.* 95 cc./min.). Elemental analyses were performed by Mr. Joseph Walter.

[25] "Technique of Organic Chemistry," A. Weissberger, Ed., Vol. II, Interscience Publishers, Inc., New York, N. Y., 1955, p. 313.

[26] (a) R. L. Shriner and R. C. Fuson, "The Systematic Identification of Organic Compounds," 3rd Ed., John Wiley and Sons, Inc., New York, N. Y., 1948, p. 163; (b) p. 171.

[27] L. Claisen and O. Eisleb, *Ann.*, **401**, 29 (1913).

[28] D. Y. Curtin, R. J. Crawford, and M. Wilhelm, *J. Am. Chem. Soc.*, **80**, 1395 (1958).

Anal. Calcd. for $C_{22}H_{21}N_2O$ (331.4): C, 79.73; H, 6.39. Found: C, 79.61; H, 6.35.

Allyl 2,6-Dimethyl-4-propenylphenyl Ether (7).—A well-stirred mixture of **6** (7.7 g., 0.047 mole, m.p. 72–76°), allyl bromide (11.8 g., 0.097 mole), potassium carbonate (9.3 g., 0.067 mole), and reagent grade acetone (25 ml.) was refluxed 24 hr. under nitrogen. Water was added to the cooled mixture, the two layers were separated, and the acetone in the organic layer was evaporated and replaced by hexane. The aqueous layer was extracted with hexane and the combined hexane solutions were washed with 5% sodium bicarbonate solution, then with water, and dried with magnesium sulfate. Evaporation left **7** as an oil (8.6 g.), which was distilled; b.p. 88–93° (0.2 mm.), $n^{20}\text{D}$ 1.5406, 6.4 g. (66%). The infrared spectrum showed ν 1645, 1587, 990, 920, 960, and 873 cm.$^{-1}$.[29]

Anal. Calcd. for $C_{14}H_{18}O$ (202.3): C, 83.12; H, 8.97. Found: C, 83.27; H, 8.81.

Catalytic Hydrogenation of 7.—A sample of **7** (0.5 g.) was hydrogenated in ethanol over platinum oxide catalyst and took up 2.08 molar equiv. of hydrogen. The catalyst was filtered off and the solvent was evaporated. The residual colorless oil (0.4 g.) exhibited, among others, a strong band at 965 cm.$^{-1}$ in the infrared spectrum (neat), which was virtually identical with the spectrum of 2,6-dimethyl-4-propylphenyl propyl ether (**8**) prepared as described below.

2,6-Dimethyl-4-propionylphenol.—Acylation of 2,6-xylenol (35.5 g.) with propionyl chloride (24 g.) by the method of Close, *et al.*,[30] gave 37 g. (71.5%) of tan crystals, m.p. 103–106°, raised to m.p. 105–108° by recrystallization from ligroin (lit.[31] m.p. 106–106.5°); $\nu^{\mathrm{CHCl_3}}$ 3636 and 1680 cm.$^{-1}$.

2,6-Dimethyl-4-propylphenol (9).—High-pressure hydrogenation of 2,6-dimethyl-4-propionylphenol (copper chromite catalyst)[32] gave an 85% yield (after distillation) of **9** as an oil, b.p. 58–60° (0.05 mm.) which solidified, m.p. 34.5–35.5° (lit.[31] m.p. 33–34°).

The α-naphthylurethan of **9** had m.p. 165–167.5° after crystallization from ligroin.

Anal. Calcd. for $C_{22}H_{23}N_2O$ (333.4): C, 79.25; H, 6.95. Found: C, 79.37; H, 6.88.

2,6-Dimethyl-4-propylphenyl Propyl Ether (8).—*n*-Propyl iodide (10.2 g.) was added dropwise to a stirred and heated solution of **9** (9.2 g.) in absolute ethanol (25 ml.) containing dissolved sodium (1.3 g.). After the solution was stirred and refluxed 4 hr., ethanol (20 ml.) was distilled off and water was added to the residue. The organic layer was taken up in petroleum ether and washed with Claisen's alkali[33] and with water and was dried over magnesium sulfate. The residue (9.5 g.) was distilled (b.p. 80° at 0.1 mm.) in a 6-cm. Hickman molecular still with ice–water as the coolant; pale yellow oil, $n^{24}\text{D}$ 1.4950, d^{25}_{4} 0.915. The infrared spectrum showed a strong band at 965 cm.$^{-1}$.

Anal. Calcd. for $C_{14}H_{22}O$ (206.3): C, 81.50; H, 10.75. Found: C, 81.64; H, 10.72.

Propyl 2,6-Xylyl Ether (10). A. By Catalytic Hydrogenation of Allyl 2,6-Xylyl Ether.—A solution of allyl 2,6-xylyl ether in ethanol was hydrogenated over platinum oxide at room temperature and atmospheric pressure. Removal of the catalyst and evaporation of the solvent left a residue, which was taken up in petroleum ether and washed with 10% sodium hydroxide solution and with water, then dried. Evaporation left a colorless oil (2 g.) which foamed excessively on attempted vacuum distillation. Determination of the boiling point by the capillary method[34] gave b.p. 221° (760 mm.). Distillation at room temperature at 2 mm. in a 6-cm. Hickman still with ice–water as coolant gave **10** as a colorless oil, $n^{25}\text{D}$ 1.4896, d^{25}_{4} 0.914. It had strong, broad infrared absorption at 965 cm.$^{-1}$.

Anal. Calcd. for $C_{11}H_{16}O$ (164.2): C, 80.44, H, 9.83. Found: C, 80.54; H, 9.75.

B. By Direct Propylation of 2,6-Xylenol.—Freshly distilled *n*-propyl iodide (51 g., b.p. 102–103°) was added dropwise to a stirred, heated solution of 2,6-xylenol (30.5 g.) in ethanol (125 ml.) containing dissolved sodium (5.8 g.). After the mixture was stirred and refluxed 3 hr., 100 ml. of ethanol was distilled off. Water was added to the residue and the organic layer was washed with 10% sodium hydroxide solution and with water, was dried over magnesium sulfate, and was evaporated. The residue (35 g.) was distilled and the fraction with b.p. 50–52° (2 mm.) was collected; 32 g. (78%). Two distillations in a 6-cm. Hickman molecular still gave **10** as a pale yellow oil, $n^{25}\text{D}$ 1.4905, d^{25}_{4} 0.915. The infrared spectrum was virtually identical with that of material prepared by method A.

2-Methylpentanoyl Chloride.—This compound was prepared in 76% yield by treatment of 2-methylpentanoic acid with thionyl chloride[35]; b.p. 134–138° (lit.[36] b.p. 140–140.8° at 745 mm.).

2,6-Dimethyl-4-(2-methylpentanoyl)phenol (11).—According to a general method[30] a solution of 2,6-xylenol (49 g., 0.4 mole) in nitrobenzene (76 ml.) was added to a stirred mixture of aluminum chloride (108 g., 0.81 mole) and nitrobenzene (210 ml.) at 10°. To this mixture was added dropwise 2-methylpentanoyl chloride (50 g., 0.37 mole) while the temperature was kept at 5–10°. After an additional 4 hr. in the ice bath, the stirred mixture was allowed to warm to room temperature and to stand overnight. It was poured onto a mixture of concentrated hydrochloric acid and ice, and the organic layer was separated and extracted with dilute sodium hydroxide solution. Neutralization of the alkaline extract gave an oil, which was taken up in ether and dried over magnesium sulfate. Removal of solvent left a dark brown residue (100 g.) that solidified. Recrystallization from light petroleum gave 60 g. of tan crystals, m.p. 78–81° (68%). Vacuum sublimation at 1 mm. and 85° followed by recrystallization from light petroleum gave **11** as colorless triangular prisms, m.p. 83–83.5°, ν^{KBr} 3330 and 1645 cm.$^{-1}$.

Anal. Calcd. for $C_{14}H_{20}O_2$ (220.3): C, 76.32; H, 9.15. Found: C, 76.64; H, 9.15.

The 2,4 dinitrophenylhydrazone of **11** was obtained conventionally[26b] and, after several recrystallizations from 95% ethanol, had m.p. 159–160°.

Anal. Calcd. for $C_{20}H_{24}N_4O_5$ (400.4): C, 59.99; H, 6.04. Found: C, 60.26; H, 5.82.

2,6-Dimethyl-4-(2-methylpentyl)phenol (12).—A mixture of **11** (11 g., m.p. 78–81°) and copper chromite catalyst (5 g., "0202P" Harshaw Chemical Co.) in absolute ethanol (70 ml.) was shaken under hydrogen at 1900 p.s.i.g. and 150° for 1.5 hr. The residue obtained after removal of the catalyst and evaporation of the filtrate under reduced pressure was distilled to give **12** (7.6 g., 76%) as a colorless oil, b.p. 85–87° (0.1 mm.), $n^{21}\text{D}$ 1.5114, m.p. 13–16°. Gas chromatography at 235° showed a single, symmetrical peak.

Anal. Calcd. for $C_{14}H_{22}O$ (206.3): C, 81.50; H, 10.75. Found: C, 81.47; H, 10.70.

The α-naphthylurethan of **12** had m.p. 154.5–155° after recrystallization from ligroin.

Anal. Calcd. for $C_{25}H_{29}N_2O$ (375.5): C, 79.96; H, 7.79. Found: C, 79.84; H, 7.60.

2,6-Dimethyl-4-aminoanisole.—2,6-Dimethylanisole was nitrated and hydrogenated as reported.[37] The amine was obtained as the sulfate which was used as such for the coupling reaction. For characterization the free amine was liberated; m.p. 64–65°, lit.[37] m.p. 63°.

3,5-Dimethyl-4-methoxybiphenyl.—A few drops of concentrated sulfuric acid were added to a suspension of 2,6-dimethyl-4-aminoanisole sulfate (12.0 g.) in water (24 ml.) at 0°. A solution of sodium nitrite (3.6 g. in 18 ml. of water) was added slowly to the stirred suspension while the temperature was kept below 5°. The diazonium solution was added to benzene (96 ml.), vigorously stirred at 5°, and to this stirred mixture a solution of sodium hydroxide (5.8 g. in 30 ml. of water) was added dropwise while the temperature was kept below 10°. The mixture was allowed to reach room temperature after 3 hr., and stirring was continued 48 hr. The benzene layer was separated, washed with water, and evaporated. The brown, tarry residue (8.0 g.) was triturated with petroleum ether, which was filtered and passed through alumina (30 g.). Elution with petroleum ether gave 2.4 g. (23%) of a yellow oil, which was distilled; b.p. 126–130° (1.5 mm.), $n^{21}\text{D}$ 1.5890. Vacuum sublimation at about 70° yielded white needles, m.p. 31–31.5°.

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(29) For assignments of infrared bands in our compounds see appropriate chapters in ref. 13.

(30) W. J. Close, B. D. Tiffany, and M. A. Spielman, *J. Am. Chem. Soc.*, **71**, 1265 (1949).

(31) K. von Auwers and E. Janssen, *Ann.*, **483**, 44 (1930).

(32) J. L. R. Williams, *J. Org. Chem.*, **22**, 772 (1957).

(33) Prepared from 350 g. of potassium hydroxide in 250 ml. of water and dilution to 1 l. with methanol.

(34) N. D. Cheronis, "Technique of Organic Chemistry," A. Weissberger, Ed., Interscience Publishers, Inc., New York, N. Y., 1954, p. 190.

(35) B. Helferich and W. Schaefer, "Organic Synthesis," Coll. Vol. I, A. H. Blatt, Ed., John Wiley and Sons, Inc., New York, N. Y., 1941, p. 147.

(36) M. Hommelen, *Bull. soc. chim. Belges*, **42**, 243 (1933).

(37) T. C. Bruice, N. Kharasch, and R. J. Winzler, *J. Org. Chem.*, **18**, 87 (1953).

Anal. Calcd. for $C_{15}H_{16}O$ (212.3): C, 84.87; H, 7.60. Found: C, 84.91; H, 7.77.

3,5-Dimethyl-4-hydroxybiphenyl (13). A. By Demethylation of 3,5-Dimethyl-4-methoxybiphenyl.—A mixture of 3,5-dimethyl-4-methoxybiphenyl (1.5 g.), glacial acetic acid (20 ml.), and 47% hydriodic acid (10 ml.) was refluxed 3.5 hr., then cooled, and poured into cold water (75 ml.). The white precipitate was collected, washed with water, and dried; 1.3 g. (93%), m.p. 91–94°. Two recrystallizations from hexane gave needles, m.p. 96.5–97°.[14]

Anal. Calcd. for $C_{14}H_{14}O$ (198.3): C, 84.81; H, 7.12. Found: C, 85.09; H, 7.35.

B. By Irradiation of 2,6-Dimethyl-4-iodophenol.—A solution of 2,6-dimethyl-4-iodophenol (0.50 g., m.p. 102–102.5°, prepared as reported)[38] in dry, reagent grade benzene (25 ml.) was placed in a quartz tube equipped with a water-cooled cold finger and was irradiated externally with a 250-w. mercury lamp for 21 hr.[16] The benzene solution was washed with 5% sodium thiosulfate solution and evaporated. The residue was chromatographed over alumina (10 g.) and eluted with 1:1 benzene–ether. The infrared spectrum of the eluted product (0.35 g.) indicated the presence of starting material; so it was dissolved in benzene (80 ml.) and reirradiated for 16 hr. The solution was worked up and chromatographed as before. Elution with 100 ml. of benzene–ether (9:1) gave solid **13** (0.045 g.), whose infrared spectrum was virtually identical with that of the material from method A. Recrystallization from hexane gave crystals with m.p. 93.5–95°, undepressed on mixture with **13** obtained from method A.

The 3,5-dinitrobenzoate of **13** was obtained by treatment with 3,5-dinitrobenzoyl chloride in anhydrous pyridine at reflux for 30 min. The derivative was isolated, decolorized with Norit in boiling ethanol, and recrystallized from aqueous ethanol and finally from 95% ethanol; colorless needles, m.p. 183–184°.

Anal. Calcd. for $C_{21}H_{16}N_2O_6$ (392.4): C, 64.29; H, 4.11. Found: C, 64.74; H, 4.25.

The α-naphthylurethan of **13** had m.p. 220.5–221.5° after recrystallization from carbon tetrachloride.

Anal. Calcd. for $C_{15}H_{21}NO_2$ (367.4): C, 81.72; H, 5.76. Found: C, 81.79; H, 5.93.

Allyl 2,6-Dimethyl-4-phenylphenyl Ether (14).—To a flask equipped with a magnetic stirrer was added **13** (2.4 g., m.p. 91–94°), allyl bromide (3.0 g.), anhydrous potassium carbonate (2.0 g.), and sufficient reagent grade acetone to give an easily stirred mass. After the stirred mixture was refluxed 24 hr., water was added, and the solution was extracted with three 30-ml. portions of ether. The combined ether extract was washed with two 50-ml. portions of Claisen's alkali, then with two 50-ml. portions of water, and was dried over potassium carbonate. Evaporation left a pale yellow oil (2.8 g.), which solidified when cooled; m.p. 32.5–34.5°. Chromatography on alumina (25 g.) and elution with petroleum ether removed the color and gave 2.4 g. (83%), m.p. 33.5–34.5°. The analytical sample of **14** (m.p. 34.5–35°) was obtained by vacuum sublimation at about 70°; ν^{CS_2} 1647, 988, 750, and 690 cm.$^{-1}$.

Anal. Calcd. for $C_{17}H_{18}O$ (238.3): C, 85.67; H, 7.61. Found: C, 86.02; H, 7.86.

2,4-Dimethyl-6-iodophenol.—To a well-stirred suspension of 2,4-xylenol (38 g.) in 14% ammonium hydroxide solution (1.2 l.) was added dropwise (over 2 hr.) a solution of iodine (48 g.) and potassium iodide (120 g.) in water (1 l.). The mixture was stirred an additional 3 hr., acidified with concentrated hydrochloric acid, and extracted with ether. When dried over magnesium sulfate and evaporated, the ether left a dark oil (54 g.) which was taken up in light petroleum and was washed with 5% sodium thiosulfate solution and then with water, and was dried. Evaporation gave the product as a yellow oil, which was distilled. The highest boiling fraction (colorless) was collected; 15 g. (20%), b.p. 64–65° (0.1 mm.), $n^{26}D$ 1.6060, d^{23}_4 1.695. Gas chromatography at 168° showed a single, symmetrical peak. Heicken[38] reports only that 2,4-dimethyl-6-iodophenol is a pale yellow oil with b.p. 123–124° at 16 mm.

2-Hydroxy-3,5-dimethylbiphenyl (15).—A solution of 2,4-dimethyl-6-iodophenol (8.2 g.) in 800 ml. of reagent grade benzene was distilled until 50 ml. had been removed. The solution was cooled and while being magnetically stirred it was irradiated in a water-cooled flask with a 200-w. Hanovia mercury lamp contained in a quartz well that protruded into the solution. An aliquot removed from the dark purple solution after 24 hr. was worked up and indicated that some starting material remained. Copper was added as an iodine scavenger, and the irradiation was continued for 12 hr. more. The benzene was distilled from the irradiated solution and the residue was chromatographed over alumina (100 g.) and eluted in eight fractions of 200 ml. each by means of hexane–benzene (9:1). Infrared examination of individual fractions indicated the absence of starting material. The pooled fractions (3.4 g., 52%; 58% when corrected for aliquot withdrawals) were distilled and the bulk was obtained as a colorless oil; b.p. 100–104° (0.1 mm.); $n^{20}D$ 1.5955; ν (neat) 3509, 860, 783, 760, 735, and 702 cm.$^{-1}$.

Anal. Calcd. for $C_{14}H_{14}O$ (198.3): C, 84.81; H, 7.12. Found: C, 84.99; H, 7.19.

The phenylurethan of **15** had m.p. 131.5–132° after numerous recrystallizations from ligroin.

Anal. Calcd. for $C_{21}H_{19}NO_2$ (317.4): C, 79.47; H, 6.03. Found: C, 79.79; H, 6.04.

The α-naphthylurethan of **15** had m.p. 126–127.5° after recrystallization from ligroin.

Anal. Calcd. for $C_{25}H_{21}NO_2$ (367.4): C, 81.72; H, 5.76. Found: C, 81.82; H, 5.84.

Allyl 2,4-Dimethyl-6-phenylphenyl Ether (16).—To a flask equipped with a magnetic stirrer was added **15** (3.3 g.), allyl bromide (4.0 g.), anhydrous potassium carbonate (2.8 g.), and sufficient reagent grade acetone to give an easily stirred mass. After the mixture was stirred and refluxed 24 hr., water was added and the mixture was extracted with three 30-ml. portions of hexane. The combined extract was washed with two 50-ml. portions of water, dried with magnesium sulfate, and evaporated. The oil (3.6 g.) was chromatographed on alumina (50 g.) and eluted with hexane (450 ml.). Evaporation left 3.4 g. (85%) of colorless liquid ether **16**, which was distilled; b.p. 100–106° (0.04 mm.); $n^{22}D$ 1.5690; ν (neat) 1647, 995, 926, 859, 765, 750, and 697 cm.$^{-1}$.

Anal. Calcd. for $C_{17}H_{18}O$ (238.3): C, 85.67; H, 7.61. Found: C, 85.84; H, 7.34.

3,5,3′,5′-Tetramethyl-4,4′-dihydroxybiphenyl (17).—The radical-induced oxidation of 2,6-xylenol by the method of Walling and Hodgdon[17] gave 3,5,3′,5′-tetramethyl-4,4′-diphenoquinone, 192–193° dec., lit.[17] m.p. 207–217° dec. (dependent on rate of heating). Reduction of the quinone with zinc in glacial acetic acid according to Cosgrove and Waters[18] gave the diol **17**, m.p. 223–223.5° (from methanol), lit.[18] m.p. 221°.

The diacetate of **17** was obtained by treatment on the steam bath (10 min. with acetyl chloride in anhydrous pyridine). The crude product was chromatographed on alumina and eluted with benzene; m.p. 169–170°; lit. m.p. 172°,[18] 174–175°.[23]

3,5,3′,5′-Tetramethyl-4-allyloxy-4′-hydroxybiphenyl (18).—Reagent grade acetone (10 ml.) was added to allyl bromide (8.5 g., 0.07 mole), diol **17** (7.5 g., 0.03 mole), and anhydrous potassium carbonate (9.7 g., 0.07 mole), and the mixture was stirred and refluxed for 7 hr. Water (60 ml.) was added, the mixture was extracted with three 20-ml. portions of ether, and the combined extract was washed with three 25-ml. portions of 10% sodium hydroxide solution and finally with two 25-ml. portions of water. Acidification of the combined wash solutions with acetic acid gave 3.3 g. of the starting diol **17**. The ether was dried over magnesium sulfate and evaporated to yield 3.5 g. (72%, corrected for recovered starting material) of crude yellow product. Recrystallization from petroleum ether gave m.p. 101–101.5° (1.5 g.). For analysis, the monoether **18** was chromatographed over alumina and then recrystallized from petroleum ether; m.p. 102–102.5°; ν^{CHCl_3} 3630, 1653, 990, and 930 cm.$^{-1}$.

Anal. Calcd. for $C_{19}H_{22}O_2$ (282.4): C, 80.82; H, 7.85. Found: C, 80.72; H, 7.89.

The acetate of **18** was obtained in 73% yield by treatment with acetyl chloride in dry pyridine on the steam bath for 10 min. Normal work-up was followed by chromatography on alumina and crystallization from petroleum ether; m.p. 112.5–113.5°; ν^{CS_2} 1754, 1205, 985, 918, and 858 cm.$^{-1}$.

Anal. Calcd. for $C_{21}H_{24}O_3$ (324.4): C, 77.75; H, 7.46. Found: C, 77.27; H, 7.31.

The same product (m.p. 111.5–113°) was obtained in 90% yield by acetylation of **18** with acetic anhydride in the presence of sodium acetate.

3,5,3′,5′-Tetramethyl-4,4′-diallyloxybiphenyl (19).—A mixture of **17** (9.6 g., 0.04 mole), allyl bromide (19.4 g., 0.16 mole), anhydrous potassium carbonate (13.8 g., 0.1 mole), and reagent grade acetone (20 ml.) was stirred at reflux. After 12 hr. more allyl bromide (2 ml.) and acetone (5 ml.) were added and the

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[38] K. Heicken, *Angew. Chem.*, **52**, 263 (1939).

stirred solution was refluxed an additional 12 hr. Water (150 ml.) was added, the mixture was extracted with three 50-ml. portions of ether, and the combined extract was washed with three 40-ml. portions of 10% sodium hydroxide solution and with two 50-ml. portions of water, then was dried over potassium carbonate. Evaporation left 9.6 g. (76%) of the diallyl ether **19** as yellow prisms, m.p. 47–51.5°. Chromatography on alumina (285 g.) and elution with benzene–hexane (3:1) gave white prisms (8.0 g.), m.p. 52.5–53° after three recrystallizations from petroleum ether. The infrared spectrum in chloroform showed bands at 1653, 995, and 928 cm.$^{-1}$, but no absorption between 3700 and 3400 cm.$^{-1}$ (OH region).

Anal. Calcd. for $C_{22}H_{26}O_2$ (322.5): C, 81.94; H, 8.13. Found: C, 81.68; H, 8.07.

General Procedure for Ether Pyrolyses.—Allyl ethers were pyrolyzed in sealed Pyrex tubes that had been flushed with nitrogen before being sealed. The tubes were heated in a steel pipe fitted with steel screwcaps at both ends and wrapped with a heating element insulated with asbestos. About 30 min. was needed to reach pyrolysis temperatures (200–250°), and a temperature constancy of about ±5° was maintained by initial setting of a calibrated Variac. After thermal treatment the tubes were allowed to cool inside the pipe before being withdrawn and opened at room temperature.

Pyrolysis of 7.—A 1.00-g. sample of **7** in 95% ethanol (25 ml.) was heated 8 hr. The pale yellow solution was directly hydrogenated at room temperature and 1 atm. with platinum oxide catalyst. When uptake was complete (3 hr.), the catalyst was filtered off and the solvent was evaporated. The pale orange oil (0.70 g.) was chromatographed over alumina (20 g.) and eluted in fractions of 30 ml. each with solvents that ranged from hexane through benzene. A small amount of insoluble material was deposited and retained at the top of the column. Fractions 4–6 (pooled wt., 0.071 g.) were eluted with 5% benzene in hexane and showed in the infrared spectrum a weak carbonyl band at 1706 (in CS_2). Otherwise the spectrum and the retention time on gas chromatography at 173° were identical with those of authentic **12**. Fractions 7–25 were eluted with benzene–hexane (1:9 through 3:1) and contained progressively increasing proportions of 2,6-dimethyl-4-propylphenol (**9**) along with the major component **12** as evidenced from the infrared spectra and gas chromatograms of individual fractions. Gas chromatographic analysis at 173° of the pooled fractions 7–26 (0.341 g.) showed two separated, symmetrical peaks in the area ratio of 79:21. The retention times of the minor (1.9 min.) and major (3.8 min.) peaks were identical with those of authentic **9** and **12**, respectively. We determined areas by cutting and weighing peak tracings, and with mixtures of known composition we observed this method to be accurate to ±1%. In addition, the infrared spectrum (in carbon disulfide) of an artificial mixture of authentic **12** and **9** in a molar ratio of 79:21 was virtually superimposable on the spectrum of pooled fractions 7–26. Phenol **12** was isolated by preparative gas chromatography of the pooled material on a 6-ft. column packed with silicone grease on Halport F. Treatment of the collected material with α-naphthyl isocyanate and dry pyridine on the steam bath gave the α-naphthylurethan, m.p. 151.5–153°, undepressed when mixed with the authentic α-naphthylurethan of **12**. The infrared spectra (KBr) were also identical. Separately, we established that the melting point of the α-naphthylurethan of **12** is depressed on admixture with the α-naphthylurethan of **9**. Further elution of the chromatographic column with benzene afforded negligible material. Based on a liberal estimate of 30% of ketonic material in fractions 4–6, the total chromatographic product (41.2 wt. %) corresponds to molar yields of 31.8% of phenol **12**, 8.4% of phenol **9**, and 2 wt. % of unknown ketonic material.

Pyrolyses of 14. A. Without Solvent at 200°.—The allyl ether **14** (0.20 g.) was heated at 200° for 3 hr. The viscous, orange oil showed infrared absorption (in carbon disulfide) at 3600 (OH), 1720 (carbonyl), 1000, and 918 (allyl) cm.$^{-1}$. The product was chromatographed on alumina (5 g.) and eluted in ten fractions of 20 ml. each. Fractions 1–7 (eluted with petroleum ether through benzene) contained principally the starting allyl ether **14** as determined by infrared inspection of individual fractions. Their combined weight was 0.12 g. (60%). Fractions 8–10 (total 0.02 g., 14%) were eluted with benzene–ether (1:1) and were composed mainly of 3,5-dimethyl-4-hydroxybiphenyl (**13**) as indicated by infrared spectral comparison with authentic material. No bands occurred at 1000 and 920 cm.$^{-1}$ typical of the allyl group.

B. Without Solvent at 250°.—When **14** (0.130 g.) was heated 5 hr. at 250° it became dark brown and tarry and deposited some colorless crystalline material (m.p. 88–89°) on the sides of the tube. The infrared spectra (in carbon disulfide) of the crystalline material and of the tarry product were virtually identical with that of the parent phenol **13**. The entire product was chromatographed over alumina (5 g.) and eluted (in 13 fractions of 15 ml. each) with solvents that ranged from hexane through benzene–ether (9:1). Infrared inspection of individual fractions as well as of the crystalline pooled material (total wt., 0.050 g., 46%) indicated the presence of only the parent phenol **13**.

C. In Decalin.—After pyrolysis of **14** (0.25 g.) in purified decalin (10 ml.) for 8 hr. at 250°, the solution was passed through alumina (7.5 g.) and eluted (in 14 fractions of 25 ml. each) with solvents that ranged from hexane through benzene. A differential infrared spectrum of fraction 1 (decalin in the compensating cell) showed only bands at 975, 908, and 828 cm.$^{-1}$, all of which are present in the spectrum of the starting material. Fractions 6–14 (total wt., 0.16 g., 75%) were eluted with hexane–benzene (1:1) and gave pale yellow crystals. Spectra (in carbon disulfide) of the individual fractions showed no bands around 995 and 920 cm.$^{-1}$, and were virtually identical with one another and with the spectrum of phenol **13**.

D. With Maleic Anhydride.—A mixture of the allyl ether **14** (0.686 g.), freshly sublimed maleic anhydride (0.703 g.), and a trace of hydroquinone was heated at 200° for 1 hr. The dark brown mixture was warmed on the steam bath for 30 min. with a 10% solution of sodium hydroxide and was cooled and extracted twice with hexane. Acidification of the aqueous layer with concentrated hydrochloric acid gave a yellow oil, which was extracted with ether. Work-up of the ether left a glassy, yellow oil (0.955 g.), which was heated to 175° for 10 min. (to reclose the anhydride ring), then chromatographed over Fuller's earth (25 g., Loewy Drug Co.). Elution with 125 ml. of benzene gave 0.881 g. (90%) of the adduct **27**, which had m.p. 161–163° (colorless needles) after recrystallization from ligroin; ν^{KBr} 1852, 1773, 1709, 1634, 990, 922, 833, 744, and 691 cm.$^{-1}$; $\lambda^{95\%\ \mathrm{EtOH}}$ 260 mμ (ε 13,900) and 305 (2400).

Anal. Calcd. for $C_{21}H_{20}O_4$ (336.4): C, 74.98; H, 5.72. Found: C, 74.97; H, 5.96.

Catalytic Hydrogenation of Adduct 27.—Ethyl acetate (10 ml.) containing the adduct **27** (0.046 g.) was shaken under 1 atm. of hydrogen in the presence of 10% palladium-on-charcoal catalyst (0.010 g.). Hydrogenation was essentially complete in 1 hr. but was continued an additional hour (total uptake, 1.02 molar equiv.). After removal of catalyst and solvent, the product was crystallized from hexane; m.p. 166–178°. In another run the dihydro adduct (**28**) was obtained in 55% yield, fluffy white needles, m.p. 176–180° after several recrystallizations from hexane. The analytical sample (m.p. 184–184.5°, obtained from ligroin) showed ν^{KBr} 1859, 1773, 1709, 833, 750, and 692 cm.$^{-1}$; $\lambda^{95\%\ \mathrm{EtOH}}$ 260 mμ (ε 13,000) and 305 (2000).

Anal. Calcd. for $C_{21}H_{22}O_4$ (338.4): C, 74.53; H, 6.55. Found: C, 74.75; H, 6.36.

Pyrolyses of 16. A. With Sodium Carbonate.—The allyl ether **16** (0.100 g.) and sodium carbonate (0.020 g.) were heated together at 220° for 5 hr. The sodium carbonate was separated from the oily product, whose infrared spectrum in carbon disulfide was virtually identical with that of authentic parent phenol **15**. There was a strong diminution of the 926-cm.$^{-1}$ band and no absorption at 995 and 750 cm.$^{-1}$, where starting material absorbs.

The total weight of phenol **15** was 0.064 g. (77%) after removal of some insoluble material by trituration in hexane.

B. In Decalin.—A sample of ether **16** (0.25 g.) in purified decalin (10 ml.) was heated at 250° for 8 hr. The pale yellow mixture was chromatographed on alumina (8 g.) and eluted in 16 fractions of 25 ml. each with solvents ranging from hexane through benzene. Apart from fractions 1 and 2, which consisted largely of decalin, the remaining fractions had infrared spectra (in carbon disulfide) that were virtually identical with one another and with the spectrum of authentic parent phenol **15**. No bands were present at 995 and 926 cm.$^{-1}$ characteristic of starting ether **22**. Pooled fractions 3–16 (0.16 g., 76%) also showed infrared absorption virtually identical with that of phenol **15**.

Pyrolysis of 19 in Acetic Anhydride and Pyridine.—A solution of the bisether **19** (0.319 g.) in dry pyridine (2 ml.) and acetic anhydride (2 ml.) was heated at 250° for 8 hr. Methanol was added and after 30 min. it was removed under reduced pressure, and the residue was taken up in chloroform and filtered. The filtrate was washed successively with dilute hydrochloric acid, dilute sodium bicarbonate solution, and water, and the solvent was evaporated. The orange residue (0.307 g.) was chromatographed over alumina (10 g.) and eluted in 12 fractions of 25 ml. each with solvents ranging from hexane–benzene (1:1) through benzene. Fractions 1–7 when pooled had m.p. 173.5–176° (0.191 g., 59%). The infrared spectra (in carbon disulfide) of the pooled material (and of individual fractions) were identical with that of authentic diacetate of phenol **17** and showed no allyl absorptions in the 995- or 920-cm.$^{-1}$ regions. Fraction 9 (0.004 g., eluted with benzene) was dissolved in a small amount of hexane, stood overnight in the refrigerator, and yielded pale yellow crystals (m.p. 172–174°) whose infrared spectrum lacked absorption at 1754 (ester carbonyl) but had bands at 1658, 1639, 995, 929, 917, 760, and 750 cm.$^{-1}$. The ultraviolet absorption in 95% ethanol was complex: λ 227 mμ (ϵ 11,700, based on a molecular weight of 362), 254 (25,700), 290 (12,600), 337 (3200), and 346 (4000). Lack of material precluded further investigation of this minor product.

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Proximity Effects in the Decomposition of Mixed Dicarboxylic–Carbonic Anhydrides

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The preparation and properties of bis(ethylcarbonic)dicarboxylic anhydrides (I) derived from a variety of dicarboxylic acids have been investigated. There is a strong tendency for these to decompose into cyclic anhydride (path A) when a five- or six-membered ring can form. When this condition is not met, the bis(ethylcarbonic)dicarboxylic anhydrides are generally stable at room temperature although a few cases of decomposition into diester *via* path B have been noted.

It has been shown that mixed carboxylic–carbonic anhydrides prepared from a monocarboxylic acid and ethyl chlorocarbonate are surprisingly stable in a number of cases.[2] These mixed anhydrides have been isolated, the course of their heat-induced decomposition has been established, and the reaction products have been characterized.[3]

We now have found that there is a consistent pattern in the stability of bisethylcarbonic anhydrides (I) derived from a variety of dicarboxylic acids. When the carboxyl groups of the diacid are sufficiently separated, the mixed anhydrides are quite stable at ordinary laboratory conditions and are analogous to the stable, mixed anhydrides of aliphatic and aromatic monocarboxylic acids studied earlier. However, when the carboxyl groups are close together, the mixed anhydrides are not stable under these same conditions and decompose spontaneously into the cyclic anhydride (II) of the dicarboxylic acid (path A). In a few cases where the carboxylic–carbonic groups were of intermediate propinquity and cyclic anhydride formation unlikely, decomposition into diester (III) according to path B occurred. This type of carboxylic–carbonic anhydride decomposition has been observed previously.[3] As we were interested only in the factors influencing the spontaneous formation of cyclic anhydrides (path A), the course of the heat-induced decomposition of those mixed anhydrides stable at room temperature and details of ester formation *via* path B were largely ignored. (See Fig. 1.)

Throughout this investigation a standard experimental procedure, similar to the one reported previously (see ref. 3c), was used in the preparation of the bis(ethylcarbonic)dicarboxylic anhydrides (I). This involved the reaction of the diacid with ethylchlorocarbonate in tetrahydrofuran at 0 to $-10°$ using triethylamine as a hydrogen chloride acceptor and isolating the reaction products under conditions such that the temperature was never allowed above 25°. The stability of the bis(ethylcarbonic)dicarboxylic anhydride, when it did not spontaneously decompose, was determined by allowing it to stand at room temperature and noting the evolution of carbon dioxide and by periodic examination of its infrared spectrum.

The bis(ethylcarbonic)dicarboxylic anhydrides derived from suberic and sebacic acids [$R = (CH_2)_6$ and $(CH_2)_8$] were stable at room temperature for 20 days and behaved as typical stable mixed anhydrides of monocarboxylic acids. On the other hand, bis(ethylcarbonic)succinic anhydride [$R = (CH_2)_2$] was quite unstable under these same conditions and only cyclic anhydride, in 80% yield, was isolated. Bis(ethylcarbonic)glutaric anhydride [$R = (CH_2)_3$] was only moderately stable as shown by its slow decomposition after 2 days into a 55% yield of cyclic glutaric anhydride. Bis(ethylcarbonic)adipic anhydride [$R = (CH_2)_4$] proved to be considerably more stable than either the succinic or glutaric derivatives. For 10 days it remained unchanged, then carbon dioxide began to evolve. After 14 days about 50% diethyl adipate, together with polymeric anhydrides, were present.

Bis(ethylcarbonic)terephthalic anhydride ($R = p\text{-}C_6H_4\text{-}$) was stable at room temperature but bis(ethylcarbonic)phthalic anhydride ($R = o\text{-}C_6H_4\text{-}$) decomposed on isolation to give a 75% yield of phthalic anhydride.

A study of two pairs of dicarboxylic acids derived from bicyclo[2.2.2]octane and bicyclo[2.2.2]octene (IV and VI, R = H) gave added evidence to the importance of the proximity of the carboxyl groups in determining the course of the decomposition of their bis(ethylcarbonic)dicarboxylic anhydrides. In the two

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