Compound **7**, isolated as a liquid from expt 9, was tentatively identified as *n*-propyl 2,4-di-*n*-propylphenyl ether by its infrared spectrum (Table III) and the fact that relatively large amounts of both **6** and **10** were obtained in this experiment.

Thermal Cyclizations. 2-Allylphenols **24**, **25**, and **32** were cyclized to 2-methyl-2,3-dihydrobenzo[*b*]furans (**33**, **34**, and **35**,[26] respectively) when they were chromatographed in the vapor phase at an injection port temperature >270 °C. In each case there was a loss of the OH function as evidenced by both infrared and NMR spectra on the effluent product: NMR (CCl_4) for **33** δ 0.92 (t, J = 7 Hz, 3 H, CH_2CH_3), 1.2–2.0 (m, 5 H, CH_2Me plus $CHCH_3$), 2.3–3.9 (m, 4 H, 2 benzylic CH_2), 4.4–5.1 (m, 1 H, OCHMe), 6.3–7.2 (m, 3 H, aromatic); for **34** δ 1.17 [d, J = 7 Hz, $CH(CH_3)_2$] which overlaps 1.32 (d, J = 6.5 Hz, 9 H total, $OCHCH_3$), 2.3–3.5 (m, 3 H, $CHMe_2$ plus benzylic CH_2), 4.3–5.0 (m, 1 H, OCHMe), 6.4–7.0 (m, 3 H, aromatic); for **35** δ 1.0–1.5 (2 overlapping d, J = 7 Hz, 9 H, 3 Me), 2.3–3.4 (m, 3 H, $CHMe_2$ plus benzylic CH_2), 4.4–5.1 (m, 1 H, OCHMe), 6.4–7.1 (m, 3 H, aromatic).

Registry No. 1, 108-95-2; **2**, 622-85-5; **3**, 645-56-7; **4**, 71-23-8; **5**, 74663-45-9; **6**, 74663-46-0; **7**, 74463-47-1; **8**, 644-35-9; **9**, 88-69-7; **10**, 23167-99-9; **11**, 6626-32-0; **12**, 74741-50-7; **13**, 74663-48-2; **14a**, 74663-49-3; **14b**, 74663-50-6; **15**, 74663-51-7; **16a**, 74663-52-8; **16b**, 74663-53-9; **17**, 74663-54-0; **18**, 74663-55-1; **19**, 99-89-8; **20**, 74663-56-2; **21**, 74663-57-3; **22**, 71029-37-3; **23**, 74663-58-4; **24**, 73295-87-1; **25**, 74663-59-5; **26**, 74663-60-8; **27**, 74663-61-9; **28**, 942-58-5; **32**, 3354-56-1; **33**, 74663-62-0; **34**, 74663-63-1; **35**, 74663-64-2; 1-bromopropane, 106-94-5; allyl bromide, 106-95-6.

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(26) This compound was reported by Kawai and Tsutsumi[16] from refluxing **32** with HBr–HOAc.

Alumina-Catalyzed Reactions of Hydroxyarenes and Hydroaromatic Ketones. 10. Reaction of Phenol with 2-Propanol[1a]

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At 300–350 °C in the presence of alumina, phenol (**1**) reacts with excess 2-propanol (**37**) to give mixed monopropyl-, dipropyl-, and 2,4,6-triisopropyl- (**42**) phenols. At 300 °C the principal components of the product mixture are 2-isopropylphenol (26–30 mol % yield) and 2,6-diisopropylphenol (44–52%); at 350–400 °C, they are the isomeric monoisopropylphenols (50–60%). With 3-isopropylphenol as substrate (instead of **1**), 2,5-diisopropylphenol is obtained (79%), while 4-isopropylphenol gives 2,4-diisopropylphenol and **42** (70% combined yield). In various runs, 0–20% of the propyl groups introduced are *n*-propyl ones. It is proposed that the principal products result from an S_N2-type reaction mechanism which involves nucleophilic attack (variously by C-2, C-4, and C-6) of an adsorbed ambident phenoxide ion onto C-2 of an adsorbed isopropoxide group. *n*-Propylation is ascribed to a side reaction of S_N1 type.

In the preceding paper[2] we reported the alumina-catalyzed reactions of phenol (**1**), *n*-propyl phenyl ether (**2**), and 4-*n*-propylphenol (**3**) with 1-propanol in the temperature range of 250–350 °C. Phenol underwent mainly (>90%) C-alkylation to form mono- to penta-*n*-propylphenols plus some O-alkylation to yield *n*-propyl aryl ethers. Substrates **2** and **3** gave similar results. On the average, 2–3 propyl groups were introduced per molecule and only 3% of these were isopropyl, instead of *n*-propyl ones. It was proposed that *n*-propylation of **1** involves an initial S_N2-type attack of an adsorbed ambident phenoxide ion onto C-1 of an adsorbed *n*-propoxide group, while isopropylation results from a side reaction of S_N1 type.

The present paper extends our study to the use of 2-propanol (**37**) or propene (**38**) as the propylating agent and to an investigation of the pathway for interconversion of *n*-propyl and isopropyl groups in the reactions. Phenol, 3-isopropylphenol (**36**), and 4-isopropylphenol (**19**) were used as substrates with **37** in the temperature range of 300–400 °C. Only **1** was reacted with **38**. A single alumina catalyst, F,[3] fresh for each experiment, was employed. Results with **37** and **38** are presented in Table I, while reactions of **2**, 2-*n*-propylphenol (**8**), and 2-isopropylphenol (**9**) in an inert solvent (benzene) without added propylating agent are shown in Table II.[5]

Results and Discussion

Inspection of Table I shows that under the reaction conditions used an average of 1–1.8 propyl groups were introduced into the benzene rings of substrates **1**, **19**, and **36**. No O-alkylation occurred, in contrast to the situation for reaction of **1** and 4-*n*-propylphenol (**3**) with 1-propanol.[2] In expt 1–4, phenol plus 2-propanol gave mono-, di-, and tripropylphenol products. Only isopropyl groups were found in the product mixture at 300 °C, but above this temperature significant quantities of *n*-propyl groups were also present (ca. 10% of the total propyl groups at 350 °C and 20% at 400 °C, expt 5). Changing the molar ratio of 2-propanol to phenol in the reaction mixture from 20:1 to 40:1 had relatively little effect on the product distribution. In contrast, changing the reaction temperature affected the positions of substitution markedly. At 300 °C isopropylation occurred with high selectivity for substitution ortho to the phenolic group. Thus, phenol (expt 1 and 2) gave **9** (26–30%) and **41** (44–52%), 3-isopropylphenol (expt 6) produced a particularly high yield of **40** (79%), and 4-isopropylphenol (expt 7) was largely converted into **39** (28%) and **42** (43%). Contrariwise, at 350 and 400 °C substitution occurred with far less discrimination to produce the isomerically mixed monosubstituted phenols **9**,

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(1) (a) This investigation was supported by Research Grant No. CA-5969 from the National Cancer Institute, U.S. Public Health Service. (b) Research Assistant, 1964–1967.

(2) L. H. Klemm and D. R. Taylor, *J. Org. Chem.*, preceding paper in this issue.

(3) The same designation of F for this catalyst was used in the preceding paper[2] in this series. Both F and C (a catalyst employed in earlier studies)[4] were Houdry HA-100 alumina, but they differ from one another in the manner of pretreatment *in our laboratory*. Thus, C was preheated at 650 °C and then cooled to the reaction temperature, while F was not heated above the reaction temperature employed.

(4) L. H. Klemm, J. Shabtai, and D. R. Taylor, *J. Org. Chem.*, **33**, 1480, 1489, 1494 (1968).

(5) To facilitate correlation with the preceding paper,[2] the same system of numbering compounds is used in both papers.

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Table I. Alumina-Catalyzed Reactions of Phenol (**1**), 3-Isopropylphenol (**36**), and 4-Isopropylphenol (**19**) with 2-Propanol (**37**) or Propene (**38**)[a]

parameter	expt no. 1	2	3	4	5	6	7	8[b]
reaction temp, °C	300	300	350	350	400	300	300	350
substrate	**1**	**1**	**1**	**1**	**1**	**36**	**19**	**1**
molar ratio used (**37**/substrate)	20	40	20	40	40	20	40	40[c]
conversion of substrate, %	100	100	100	100	100	94	94	68
liquid product component, mol % yield[d]								
2-*n*-propylphenol (**8**)			3.8	3.9	9.1			1.7
2-isopropylphenol (**9**)	25.7	29.9	29.0	22.6	21.5	1.3	8.5	2.4
3(and 4)-isopropylphenol (**36, 19**)[e]	4.7[f]	2.2	31.6	27.9	28.7			10.3
4-*n*-propylphenol (**3**)			6.8	6.4	10.0			3.0
2,4-diisopropylphenol (**39**)	9.6	4.1	6.2	9.2	4.5	2.6	27.8	1.0
2,5-diisopropylphenol (**40**)	7.9	3.9	6.8	8.1	4.5	79.2	7.0	0.8
2,6-diisopropylphenol (**41**)	43.8	51.7	4.9	6.4	3.2		2.8	0.4
2,4,6-triisopropylphenol (**42**)	7.8	8.4	0.9	1.4		2.2	42.6	
unidentified (wt %)[g]			(9.0)	(13.9)	(11.4)[h]	(5.0)[i]	(5.5)	(5.1)[j]
extent of propylation[k]	1.8	1.8	1.2	1.3	1.1	1.0[l,m]	1.4[m]	1.1

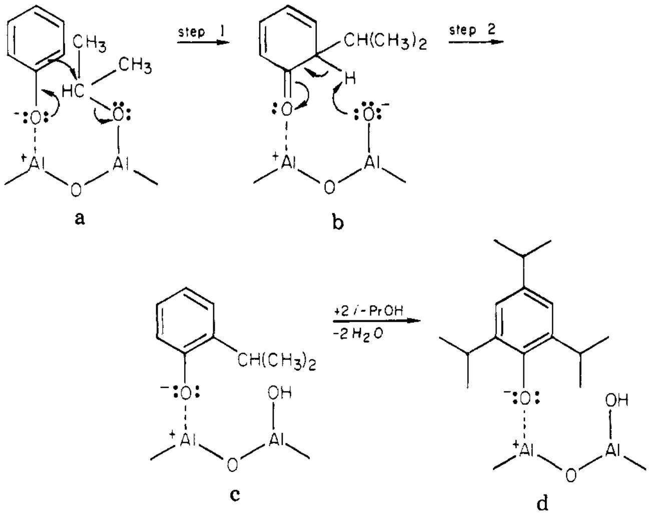
[a] Houdry HA-100 alumina, designated F, was used in each experiment.[3] [b] No propanol was used in this experiment. Instead, **1** was added in benzene solution, while propene was introduced into the nitrogen carrier gas stream (see Experimental Section). [c] Molar ratio of **38**/**1**. [d] The mole % yield shown is based on the assumption that *all* of the substrate charged does react. Hence, the summation of yields of identified liquid product components will equal (but not exceed) the percent conversion of substrate only where there are no unidentified gaseous, liquid, or solid byproducts. [e] This mixture gives a single peak in VPC (cf. Experimental Section). [f] By ^{1}H NMR analysis, this mixture was found to contain a ratio of **36**/**19** of ~2/3. [g] Includes all unidentified VPC peaks, of which the largest is <5% (by weight) of the total liquid product obtained. Gaseous, nondistillable liquid, and solid products (e.g., carbonaceous deposits left on the catalyst) are not included in this number. [h] There is appreciable carbonization at 400 °C. [i] Additionally, 2.6 mol % of phenol is formed. [j] Also, 44% of the phenol which reacted was converted into nonvolatile products. [k] Average number of propyl groups added per molecule, for identified products only. [l] Excludes phenol formed (footnote *i*). [m] In this case, the value has been adjusted to take into account the fact that the substrate molecule already bears one propyl group.

19, and **36**. In none of these cases, however, did propylation occur on a ring position vicinal to a second propyl substituent. Consequently, 2,4,6-triisopropylphenol (**42**) was the most highly substituted phenol produced, in contrast to the formation of some 2,3,4,5,6-penta-*n*-propylphenol from phenol and 1-propanol.[2]

Experiment 8 was conducted with phenol and propene (**38**) in an effort to ascertain if some of the products in expt 1–7 could be rationalized in terms of initial dehydration of 2-propanol to **38**, which then served as the propylating agent, per se. Experiment 8 used benzene (rather than propanol) as a solvent, so that the catalyst surface may have been considerably altered from that which prevailed in expt 1–7. Nonetheless, product distributions from expt 4 and 8 indicate many similarities, particularly (a) the formation of both *n*-propyl- and isopropylphenols, (b) the relatively high yield of mixed 3- and 4-isopropylphenols, and (c) the limited extent to which di- and tripropylation occur.

On the basis of the preceding results, we propose that two or more competing pathways for propylation of phenol by means of 2-propanol are extant in our experiments. The first one is dominant in the reactions at 300 °C and involves isopropylation by means of a nucleophilic attack mainly by C-2 and C-6 (less likely by C-4) of a chemisorbed ambident phenoxide ion[6] onto C-2 of a neighboring chemisorbed isopropoxy group[7] (S_N2-type mechanism). The steps involved in the formation of chemisorbed **42** are completely analogous to those proposed for formation of 2,4,6-tri-*n*-propylphenol (**14b**).[2,8] However, steric hindrance to further alkylation of **42** by 2-propanol halts the reaction at this point (Scheme I). Contrariwise, **14b** alkylates further to give penta-*n*-propylphenol,[2] while phenol plus methanol go even beyond the pentamethylphenol stage to form hexamethylcyclohexadienones and, eventually, hexamethylbenzene.[9,10] Scheme I readily accounts for the conversion of **1** into **9**, **19**, **39**, **41**, and **42**, of **19** into **39** and **42**, and of **36** into **40**, i.e., for most (if not all) of the principal products formed in expt 1–7.

Scheme I



Experiments 9–12 (Table II) were conducted in an effort to hunt for plausible intermediates in propylation pathways which compete with Scheme I. These experiments were carried out in benzene as a solvent, without propanol. Experiments 11 and 12 show that depropylation from C-2 of the benzene ring occurs and is accompanied by limited repropylation at a different position (C-4 or C-6) either intra- or intermolecularly. No interconversion of *n*-propyl

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(6) D. R. Taylor and K. H. Ludlum, *J. Phys. Chem.*, **76**, 2882 (1972).

(7) D. Treibmann and A. Simon, *Naturwissenschaften*, **53**, 107 (1966).

(8) Presumably 2,4,6-trimethylphenol forms as an intermediate from phenol and methanol in the presence of alumina in the same manner. However, in the series of all possible methyl-substituted phenols only mono-, di-,[9] and pentamethylphenols[10] have been isolated and identified from the reaction mixture.

(9) N. Cullinane and S. Chard, *J. Chem. Soc.*, 821 (1945).

(10) A. P. Krysin and V. A. Koptyug, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1596 (1969); *Chem. Abstr.*, **71**, 112540 (1969).

Table II. Alumina-Catalyzed Reactions of *n*-Propyl Phenyl Ether (2), 2-*n*-Propylphenol (8), and 2-Isopropylphenol (9) in Inert Solvent (Benzene)[a]

parameter	expt no.			
	9	10	11	12
reaction temp, °C	300	350	300	300
substrate	**2**	**2**	**8**	**9**
conversion to liquid products, %	76[b]	57[b]	35	73
liquid product component, mol % yield[c]				
phenol (**1**)	51.7	29.4	10.4	65.0
2-*n*-propylphenol (**8**)	9.0	11.7	*d*	
2-isopropylphenol (**9**)	5.4	3.4		*e*
4-*n*-propylphenol (**3**)	2.0	3.4	5.5	
4-isopropylphenol (**19**)	2.0	1.8		6.7
2,4-di-*n*-propylphenol (**10**)	0.6	0.7	4.5	
2,5-diisopropylphenol (**40**)	0.7	0.6		
2,6-di-*n*-propylphenol (**11**)	1.0	2.3	8.9	
2,6-diisopropylphenol (**41**)	0.4	0.2		
2-*i*-Pr-6-*n*-propylphenol (**13**)	0.9	0.4		
unidentified (wt %)[f]	(2.7)	(3.4)	(5.4)	
recovered propyl groups, %	25.6	28.7	32.3	6.7
ratio of *n*-Pr/total Pr groups in identified products	0.59	0.75	1.0	0

[a] See footnote *a* of Table I. [b] No substrate was recovered. [c] See footnote *d* of Table I. [d] Plus 47% recovery of **8**. [e] Plus 27% recovery of **9**. [f] Includes all unidentified VPC peaks, of which the largest is <2% by weight of the total volatile liquid product.

and isopropyl groups is apparent. It seems likely that the reaction mechanism is the same as shown in steps 1 and 2 of Scheme I in this paper and Scheme I of the preceding one[2] but involves both reverse and forward processes. Direct equilibration between *n*-propyl- and isopropylphenols apparently can be rejected as a pertinent side reaction.

In expt 9 and 10, the substrate *n*-propyl phenyl ether (**2**) is transformed into phenol, monopropylphenols, and dipropylphenols, with concurrent appreciable isomerization (41% and 25%, respectively) of the *n*-propyl groups to isopropyl ones. Again, C-propylation occurs largely at the 2-, 4-, and 6-positions, though a small amount of 2,5-diisopropylphenol is produced. The product distribution from expt 8 (using propene and phenol) resembles that from expt 10 (also conducted at 350 °C) in the positions of ring substitution, except for the presence of some 3-isopropylphenol in the former mixture. However, isopropyl groups constitute a much larger portion (78%) of the total propyl groups in the products from expt 8. Inasmuch as isopropyl phenyl ether was not detected in any experiment, it is assumed that this compound is not an intermediate.

It is proposed that the side reactions involve an S_N1-type mechanism, whereby 2-propanol is converted into the propyl carbonium ion (either directly by loss of hydroxide ion or indirectly through dehydration to propene and subsequent protonation of this intermediate). Interconversion of *n*-propyl and isopropyl carbonium ions occurs on the catalyst surface but in such manner as to result in more extensive *n*-propylation than isopropylation of the phenolic ring. Thus, the carbonium ions are not considered to be completely free to establish an equilibrium mixture (where isopropyl ones would be preferred) prior to the propylation process. The S_N1 character of the reactions of 2-propanol is consistent with (a) the observed increase in ratio of *n*-propyl/total propyl substituents and (b) the increased extent of isopropylation at C-3 and C-4 as the reaction temperature is raised. The interconversion of carbonium ions, with preference for *n*-propylation, was also apparent in experiments with 1-propanol.[2]

In contrast to our results, literature reports on propylation of phenol or phenoxide ion with 1-propanol, 2-propanol, or propene generally indicate that only isopropyl substituents enter the ring. Under conditions presumed to yield free carbonium ions (anhydrous HF at 2–25 °C), phenol plus 2-propanol gave a 95% yield of **42**.[11] Similarly, phenol plus propene, in the presence of sulfuric acid or the H form of KU-2 cation exchange resin, gave 50% and 91% yields of **42**, respectively.[12] With liquid HF in CCl_4, phenol plus propene formed isopropyl phenyl ether plus mono-, di-, and triisopropylphenols.[13] Refluxing phenol and either 1- or 2-propanol with boron trifluoride gave the same mixture of **9**, **19**, and isopropyl 2,4-diisopropylphenyl ether.[14] Various other examples with similar results have been reported.[15,16] A notable exception to this general observation is the report[17] that the action of excess aluminum chloride on a mixture of phenol and 1-propanol at 120–140 °C gave the *n*-propyl derivatives **3** and **8** and an *n*-propyl *n*-propylphenyl ether.

Of particular interest to the present research are reported studies which involve heterogeneous catalysts. By use of alumina as a catalyst at 280 °C and 198 atm pressure, phenol plus propene produced mono-, di-, and triisopropylphenols,[18] with substituents found only in ortho and para positions. Similar results were obtained from propene plus aluminum phenoxide above 200 °C in an autoclave,[19] except that ortho substitution was markedly preferred. Treatment of phenol with 1-propanol (1:2 molar ratio) and alumina at 400 °C in an autoclave (130 atm) gave **2**, **8**, and *n*-propyl 2-*n*-propylphenyl ether (**5**), but in a flow system at 450–500 °C (1 atm) only **2**, propene, and a brown, oily condensate were obtained.[20] With 2-propanol and alumina at 200–300 °C in a flow system, phenol gave both C- and O-propylation, but the structure of the propyl groups was not indicated,[21] while with silica–alumina catalyst, **9**, **19** (combined yields 95%), and diisopropylphenols resulted.[22] In general, these data seem consistent with our findings, if one assumes that minor amounts of products (from meta substitution or propyl group isomerization) were not detected[23] or were ignored. From our experiments it is clear that one need not conduct the reaction at elevated pressure in order to obtain reasonable yields of propylated phenols.

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[11] W. S. Calcott, J. M. Tinker, and V. Weinmayr, *J. Am. Chem. Soc.*, **61**, 1010 (1939).

[12] I. G. Gakh, E. P. Babin, and L. G. Gakh, *Tr., Vses. Nauchno-Issled. Inst. Khim. Reakt. Osobo Chist. Khim. Veshchestv*, **29**, 319 (1966); *Chem. Abstr.*, **67**, 53814 (1967).

[13] V. I. Korenskii, V. G. Plyumin, I. V. Butina, A. P. Lysenko, and N. A. Shevchenko, *Tr. Inst. Khim., Akad. Nauk SSSR, Ural. Fil.*, No. 16, 34 (1968); *Chem. Abstr.*, **70**, 87191 (1969).

[14] F. J. Sowa, G. F. Hennion, and J. A. Nieuwland, *J. Am. Chem. Soc.*, **57**, 709 (1935).

[15] S. H. Patinkin and B. S. Friedman, "Friedel-Crafts and Related Reactions", Vol. 2, G. A. Olah, Ed., Interscience, New York, 1964, Part 1, pp 197–198; A. Schriesheim, *ibid.*, p 566.

[16] V. K. Kuskov and G. F. Fillippova, *Zh. Obshch. Khim.*, **29**, 4063 (1959); *Chem. Abstr.* **54**, 20942*f* (1960).

[17] I. P. Tsukervanik and Z. N. Nazarova, *J. Gen. Chem. USSR (Engl. Transl.)*, **7**, 623 (1937); *Chem. Abstr.*, **31**, 5778 (1937).

[18] W. Hahn, German Patent 1142873; *Chem. Abstr.*, **58**, 12468*g* (1963); W. Hahn, Belgian Patent 612901; *Chem. Abstr.*, **57**, 13683*h* (1962).

[19] R. Stroh, R. Seydel, and W. Hahn, *Angew. Chem.*, **69**, 699 (1957); "Newer Methods of Preparative Organic Chemistry", Vol. 2, W. Foerst, Ed., Academic Press, New York, 1963, pp 342–345; A. J. Kolka, J. P. Napolitano, A. H. Filbey, and G. G. Ecke, *J. Org. Chem.*, **22**, 642 (1957).

[20] W. Ipatiew, N. Orlow, and A. Petrow, *Ber. Dtsch. Chem. Ges. B*, **60**, 1006 (1927).

[21] N. Ohta, *Kogyo Kagaku Zasshi*, **51**, 141 (1948); *Chem. Abstr.*, **44**, 9226*d* (1950).

[22] M. B. Turova-Pollak, N. V. Rudenko, and L. D. Lin, *Zh. Obshch. Khim.*, **30**, 94 (1960); *Chem. Abstr.*, **54**, 20942*e* (1960).

[23] At least most (if not all) of the previous studies were made without the benefit of gas chromatographic analysis of products.

Experimental Section[24]

Procedure. The reactions were conducted in the flow system previously described,[2] but only with alumina catalyst F[3] (Houdry HA-100, containing 0.4% sodium ion). Experiments 1–7 involved the use of 2-propanol as solvent and propylating agent. In expt 8 a solution of 2 g of phenol in 56 mL of benzene was added dropwise to the preconditioned catalyst while a mixture of nitrogen (33 mL/min)[25] and propene (117 mL/min)[25] was passed through the catalyst bed. Processing of the effluent as before gave 0.32 g of neutral, dark brown liquid. In expt 9–12 a solution of 6.9 g of substrate in 44 mL of benzene was added dropwise to the catalyst, but the gas stream consisted of nitrogen only. Product mixtures were collected as before[2] and analyzed quantitatively by VPC at 150 °C (isothermally) on a 1 cm × 2.4 m column of Chromosorb W (60–80 mesh) impregnated with 10% DC-550 silicone oil. Accuracy and reproducibility were noted previously.[2] All starting materials were available from commercial sources. Data for the various experiments are presented in Tables I and II.

Isolation and Identification of Reaction Products. All of the products listed in Tables I and II were isolated from one or more crude reaction mixtures by preparative VPC as colorless liquids. They were variously identified by direct comparison with authentic reference samples (retention time, infrared and ^{1}H NMR spectra), by comparison with literature data on infrared spectra,[26] and by elemental analysis. Previously unreported NMR spectral data (CCl_4) are as follows. For 2,4-diisopropylphenol (**39**): δ 1.20 [d, J = 7 Hz, 2 $CH(CH_3)_2$], 2.78 and 3.17 (2 overlapping pentets, J = 7 Hz, 2 $CHMe_2$), 5.24 (s, OH), 6.47 (d, J = 8 Hz, H-6), 6.78 (dd, J = 8, 2 Hz, H-5), 6.93 (d, J = 2 Hz, H-3). For 2,5-diisopropylphenol (**40**): δ 1.12 and 1.17 [2 overlapping d, J = 7 Hz, 2 $CH(CH_3)_2$], 2.68 and 3.18 (2 overlapping pentets, J = 7 Hz, 2 $CHMe_2$), 5.68 (s, OH), 6.46 (d, J = 1.8 Hz, H-6), 6.70 (dd, J = 8, 1.8 Hz, H-4), 7.05 (d, J = 8 Hz, H-3). For 2,6-diisopropylphenol (**41**): δ 1.20 [d, J = 6.5 Hz, 2 $CH(CH_3)_2$], 3.08 (6 peaks of septet, 2 $CHMe_2$), 4.69 (s, OH), 6.5–7.1 (m, 3 aromatic H). For 2,4,6-triisopropylphenol (**42**): δ 1.19 [d, J = 7 Hz, $CH(CH_3)_2$ at C-4] which overlaps 1.23 [d, J = 7 Hz, $CH(CH_3)_2$ at C-2 and C-6], 2.5–3.4 (m, 3 $CHMe_2$), 4.44 (s, OH), 6.81 (s, 2 aromatic H).

Registry No. 1, 108-95-2; **2**, 622-85-5; **3**, 645-56-7; **8**, 644-35-9; **9**, 88-69-7; **10**, 23167-99-9; **11**, 6626-32-0; **13**, 74663-48-2; **19**, 99-89-8; **36**, 618-45-1; **37**, 67-63-0; **38**, 115-07-1; **39**, 2934-05-6; **40**, 35946-91-9; **41**, 2078-54-8; **42**, 2934-07-8.

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[24] See note 17, ref 2.

[25] Measured at room temperature and pressure.

[26] D. D. Shrewsbury, *Spectrochim. Acta*, 16, 1294 (1960).

Applications of Carbon-13 Nuclear Magnetic Resonance Spectroscopy. 24.[†] The Spectra of Cyclopropane-Annelated Bicyclo[2.2.2]octanes, Three-Membered-Ring Effects and Chemical Shift Nonequivalence

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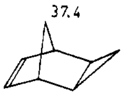
The ^{13}C NMR spectra of cyclopropane-annelated bicyclo[2.2.2]octanes have been measured and the three-membered-ring effect on carbon chemical shifts was determined. The unusual deshielding mechanism operative for the methano bridge in cyclopropane-annelated norbornanes is absent for an ethano bridge. The sensitivity of ^{1}H and ^{13}C for the intrinsic anisochronism of the "propeller-shaped" trishomobarrelene system was studied, using various prochiral groups.

Introduction

The peculiar bonding situation in cyclopropane has been revealed by various spectroscopic techniques and a recent addition to the long list of remarkable observations[1] is the unusual substituent effect exerted by an annelated cyclopropane ring on the carbon-13 chemical shifts in a number of polycyclic compounds. Tori et al.,[2] for example, reported strong shielding and deshielding, respectively, for the C-7 resonance in the isomeric tricyclooctenes **1** and **2** if compared to the unsubstituted reference compound norbornene (**3**), and Christl[3] observed both effects intramolecularly in tetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptane (**4**) as he compared the ^{13}C chemical shifts of this compound with those of tricyclo[3.1.0.0^{2,6}]hexane (**5**).



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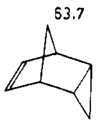

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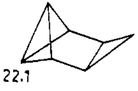

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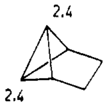

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Whereas the shielding can be classified empirically as a typical γ-effect, the deshielding seems to operate through charge transfer from the σ framework to the antibonding Walsh orbital (A_2')[4] of the three-membered ring. A qualitative MO model (Figure 1) nicely explains these findings.[3] It also accounts for the results found for C-7 in *endo*-epoxynorbornane and -norbornene.[5] In addition,

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[†] For Part 23 see H. Günther and A. Gronenborn, *Heterocycles*, 11, 337 (1978).

[1] For reviews see: (a) D. Wendisch, *Methoden Org. Chem.* (Houben-Weyl), 4/3, 1971; (b) A. de Meijere, *Angew. Chem.*, 91, 867 (1979); *Angew. Chem., Int. Ed. Engl.*, 18, 809 (1979).

[2] K. Tori, M. Ueyama, K. Tsuji, H. Matsumura, and H. Tanida, *Tetrahedron Lett.*, 327 (1974).

[3] M. Christl, *Chem. Ber.*, 108, 2781 (1975).

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