[CONTRIBUTION FROM THE CHEMICAL & PHYSICAL RESEARCH LABORATORIES OF THE FIRESTONE TIRE & RUBBER COMPANY]

Terpene Phenols and Phenol Ethers

BY LELAND J. KITCHEN

Terpene phenols, nuclearly alkylated phenols containing terpenyl groups as substituents, have been prepared previously by alkylation of phenols with terpenes and with terpenyl halides. Koenigs[1] noticed that turpentine readily reacted with phenol and with resorcinol in the presence of sulfuric acid–acetic acid catalyst. Wuyts[2] recognized that the reaction of terpenes with phenols led to mixtures of terpenyl ethers of phenols, and phenols nuclearly alkylated with terpenyl groups. The products for the most part were resinous and very few crystalline terpenyl phenols have been reported. Roblin and Hechenbleikner[3] obtained a crystalline "bornyl phenol" of m. p. 109° by alkylating phenol with bornyl chloride.

It has now been found that isobornyl ethers of phenols can be prepared in high yields by condensing camphene with phenols in the presence of an acid catalyst such as boron trifluoride at relatively low temperatures.

When heated with the catalyst the ethers rearranged to give isobornyl phenols along with some of the original unalkylated phenol. The isobornyl ether of phenol gave some free phenol, monoisobornylphenol, and resinous fractions corresponding in boiling point to diisobornylphenol and triisobornylphenol. The isobornyl ether of *p*-cresol yielded, on rearrangement, some *p*-cresol, 2-isobornyl-4-methylphenol, and a resinous product corresponding in boiling point to 2,6-diisobornyl-4-methylphenol. In the case of isobornyl 2,4-dimethylphenyl ether, with only one rearrangement product possible, a good yield of 2,4-dimethyl-6-isobornylphenol, a crystalline solid, was obtained.

Nopinene, carefully reacting with 2,4-dimethylphenol at relatively low temperature, gave a small yield of a mixture of terpene 2,4-dimethylphenyl ethers of high rotation. This product, b. p. 175.5–184° (10 mm.), similar in properties to isobornyl 2,4-dimethylphenyl ether, may have contained bornyl 2,4-dimethylphenyl ether; it could not be crystallized. Subjected to rearrangement by boron trifluoride at elevated temperature, it yielded free 2,4-dimethylphenol, a monocyclic terpine fraction, some polymeric residue, and *ca.* 27% yield of monocyclic terpene ethers of 2,4-dimethylphenol. However, in one nopinene–dimethylphenol reaction in which the temperature rose to 140°, the reaction products included nopinene polymer (41%), monocyclic terpene ethers of 2,4-dimethylphenol (32%) and, unexpectedly, 9% 2,4-dimethyl-6-isobornylphenol.

The present results with camphene and nopinene are in disagreement with the literature. It was found in the present work that ethers were obtained at low temperature, *e. g.*, −10 to +20°, whereas elevated temperatures, 80–100°, led to nuclear alkylation. Zink[4] stated that C–C condensation predominates at 1–35° and ether formation at 100–160°. Wuyts[2] reported similar results.

Isobornyl ethers prepared in the present work included the ethers of phenol, *p*-cresol, 3,5-dimethylphenol and *p*-fluorophenol, which were liquids; and the ethers of *o*-cresol, 2,4-dimethylphenol, *p*-methoxyphenol, *p*-*t*-amylphenol and 2,4-dichlorophenol, which were solids.

With low catalyst concentration (0.05–0.1% boron trifluoride-ether or 2% benzenesulfonic acid), the yields of isobornyl 2,4-dimethylphenyl ether were nearly quantitative.

The same catalysts in larger amounts also were effective for carrying out the rearrangement at elevated temperature, though best yields were obtained with boron trifluoride.

In a study of several solvents as mediums for the rearrangement reaction, benzene appeared somewhat better than cyclohexane or carbon tetrachloride, and dioxane completely inhibited the catalytic activity of the boron trifluoride catalyst.

Experimental

Isobornyl Ethers from Camphene and Phenols.—The camphene used in these experiments, supplied by Nelio Resin Processing Corp. of Jacksonville, Fla., had low rotation ($[\alpha]^{24}D$ −4.35° (ether)). Camphene was mixed with an equivalent amount of the phenol to be etherified; in some cases a small amount of diluent was added. To the stirred solution, cooled in an ice–concd. hydrochloric acid bath, was added slowly about 1% its weight of catalyst (45% boron trifluoride in ether) at a rate such that the temperature did not rise above 5–10°; thirty to sixty minutes was required for catalyst addition. After about another hour the reaction mixture was treated with 5% sodium hydroxide solution to remove catalyst and unreacted phenol. The oil layer was distilled through a 1-ft. column packed with Raschig rings.

The isobornyl aryl ethers distilled as colorless, somewhat viscous liquids. Several of them crystallized on cooling. The preparation and properties of the ethers are described in Table I.

2,4-Dimethyl-6-isobornylphenol by Rearrangement of Isobornyl 2,4-Dimethylphenyl Ether.—One kilogram of the recrystallized ether dissolved in 500 ml. of benzene was refluxed for five hours with 10 g. of BF_3–ether catalyst. Reaction was so vigorous at first that water-bath cooling was necessary. The reaction mixture, extracted with 5% sodium hydroxide to remove catalyst and dimethylphenol, was analyzed by fractional distillation; yields of products were 2,4-dimethyl-6-isobornylphenol, 87%; unreacted ether, 5%; 2,4-dimethylphenol, 1.2%; and residue, 3.7%. The product boiled mainly at 193.5–196.5° (10 mm.); it

---

(1) W. Koenigs, *Ber.*, **24**, 179 (1891).

(2) H. Wuyts, U. S. Patent 1,469,709 (1923).

(3) R. O. Roblin, Jr., and I. Hechenbleikner, U. S. Patent 2,311,282 (1943).

(4) R. Zink, U. S. Patent 2,186,132 (1940).

TABLE I

PREPARATION AND PROPERTIES OF ISOBORNYL PHENYL ETHERS

Substituted phenyl	Catalyst,[a] %	Time, hr.	Yield, %	B. p., °C.	B. p., °C. (10 mm.)	$n^{20}D$	d^{20}_4	Percentage composition Carbon Calcd.	Carbon Found	Hydrogen Calcd.	Hydrogen Found	Molar refraction Calcd.	Molar refraction Found
......	1.4	2.0	82		151[b]	1.5265[c]	1.006					69.73	70.36
4-F[d]	2.0	1.5	86		151	1.5111	1.004					70.97	71.25
2-CH_3	1.0	1.5	88	48.5–48.8[j]	164.5[m]	1.5274[n]		83.55	83.73	9.90	10.03		
4-CH_3[e]	1.3	264.0	95		164.5	1.5190	0.9833					74.35	75.43
2,4-$(CH_3)_2$	0.3[i]	2.0	90	57.6–57.8[j]	176	1.5230[n]		83.66	83.55	10.14	10.42		
3,5-$(CH_3)_2$[f]	1.3	2.5	84		173.5	1.5240	0.9843					78.96	80.32
2,4-$(Cl)_2$[g,h]	2.0	3.0	77	61.0–61.4[k]	195.5	1.5480[n]	1.176[n]	64.22	63.90	6.74	6.88	79.46	80.83
4-*t*-C_5H_{11}	0.7	2.0	86	48.8–49.2[l]	199	1.5188[n]	0.970[n]	83.94	84.15	10.74	10.91	92.82	93.96
4-OCH_3[f]	4.5	2.5	85	35.8–36.6[l]	183	1.5278[n]	1.039[n]	78.42	78.40	9.29	9.39	75.99	77.15

[a] Concentration on the reactants of 45% boron trifluoride in ether. [b] B. p. 167° (20 mm.), 295° (744 mm.). [c] $n^{25}D$ 1.5241, $n^{30}D$ 1.5221. [d] Prepared in petroleum ether soln. [e] 1.5 molar excess of camphene present during condensation. [f] Prepared in toluene soln. [g] Prepared in benzene soln. [h] Chlorine analysis, % calcd. for $C_{16}H_{20}OCl_2$: 23.70; found: 23.72. [i] Reaction was exothermic and temperature rose to 20°. Lower catalyst concentration (0.05–0.1%) with longer reaction time (one to five days) gave comparable yield. 2% benzenesulfonic acid (70%) gave 90–95% yield in fifteen hours. [j] Recrystallized from 3:1 alcohol–acetone. [k] Recrystallized from petroleum ether. [l] Recrystallized from alcohol. [m] A higher-boiling fraction, 16 g. (8.5% yield), b. p. 245° (6 mm.), was obtained as a yellow resin, probably isobornyl 2-methyl-4-isobornylphenyl ether. [n] Physical properties were determined on supercooled liquids before recrystallization.

was a highly viscous liquid with a faint yellow tinge which crystallized on cooling; $n^{20}D$ 1.5414 (supercooled liquid); b.p. 196° (10 mm.); m. p. 82.9–93.0° (soft chalky-white crystals from petroleum ether).

Anal. Calcd. for $C_{18}H_{26}O$: C, 83.66; H, 10.14; mol. wt., 258.4. Found: C, 83.27; H, 10.27; mol. wt., 258 (micro-Rast).

Effect of Solvent.—Benzene was the best diluent tested for the reaction. Several diluents were compared by heating 200 g. of isobornyl 2,4-dimethylphenyl ether dissolved in 300 ml. of diluent with 2.0 g. of boron trifluoride-ether catalyst at 90° for five and three-quarters hours. Yields of 2,4-dimethyl-6-isobornylphenol were 84% in benzene, 75% in cyclohexane, 73% in carbon tetrachloride and 61% in toluene. With dioxane as diluent no product was obtained and the starting material was recovered almost quantitatively. In a similar reaction carried out in refluxing toluene (123–126°) for eleven hours with 4 g. of 70% benzenesulfonic acid as catalyst the yield of 2,4-dimethyl-6-isobornylphenol was only 32%, while the yields of camphene and 2,4-dimethylphenol were 25 and 30%, respectively.

2,4-Dimethyl-6-isobornylphenol from Camphene and 2,4-Dimethylphenol.—Two moles each of camphene (272 g.) and 2,4-dimethylphenol (244 g.) and 8 g. of 70% benzenesulfonic acid were dissolved in 300 ml. of toluene and the mixture was refluxed nine and one-half hours (129–130°). The reaction mixture contained 55% of the reactants, a 2% yield of isobornyl 2,4-dimethylphenyl ether and a 35% yield of 2,4-dimethyl-6-isobornylphenol.

Rearrangement of Isobornyl Phenyl Ether.—Two hundred grams of isobornyl phenyl ether in 300 ml. of dry benzene was heated to reflux and 2 g. of boron trifluoride–ether was added. Vigorous reaction took place, and reflux was continued for seven hours. Catalyst and free phenol (33 g. formed, by difference) were extracted with 5% sodium hydroxide. A middle layer which formed was acidified and combined with the oil layer, which was distilled through a 1-foot fractionating column (Raschig rings). Estimated amounts of products were monoisobornylphenol, 53 g.; diisobornylphenol, 39 g.; and triisobornylphenol, 30 g. The purest fraction of *o*-isobornylphenol, 9 g. of viscous almost colorless liquid, had b. p. 179–180° (10 mm.) and $n^{20}D$ 1.5514; it crystallized on cooling to a white solid which had m. p. 77.8–78.6° after two recrystallizations (petroleum ether). *Anal.* Calcd. for $C_{16}H_{22}O$: C, 83.42; H, 9.63. Found: C, 83.87; H, 9.86. The diisobornylphenol, a yellow resin on cooling, distilled at 231–256° (5 mm.); the main portion had b. p. 251° (5 mm.), $n^{20}D$ 1.5490. Triisobornylphenol distilled from a Claisen flask, was a clear yellow brittle rosin-like solid, b. p. r. 275–325° (3 mm.).

Rearrangement of Isobornyl *p*-Cresyl Ether.—Two hundred grams of isobornyl *p*-cresyl ether, rearranged with boron trifluoride–ether catalyst in the manner described for the phenyl ether, yielded approximately 15 g. of *p*-cresol; a 2 g. forerun, b. p. 130–165° (10 mm.), $n^{20}D$ 1.5045; 27 g. of recovered isobornyl *p*-cresyl ether, b. p. 165–178° (10 mm.), $n^{20}D$ 1.5253; a 20-g. intermediate fraction, b. p. 178–187° (10 mm.), $n^{20}D$ 1.5394; 30 g. of 2-isobornyl-4-methylphenol, b. p. 187–191° (10 mm.), $n^{20}D$ 1.5437, a very viscous light yellow liquid which slowly crystallized on standing; a 6-g. intermediate fraction, b. p. 191–254° (10 mm.); 87 g. of 2,6-diisobornyl-4-methylphenol, b. p. 254–276° (10 mm.); a light yellow resin which could not be crystallized; and 11 g. of residue.

2-Isobornyl-4-methylphenol, recrystallized several times from petroleum ether, had m. p. 71.8–72.5°. *Anal.* Calcd. for $C_{17}H_{24}O$: C, 83.55; H, 9.90. Found: C, 83.16; H, 9.89.

Reaction of Nopinene with 2,4-Dimethylphenol.—Pure *l*-nopinene was prepared by fractional distillation of commercial β-pinene; it had $n^{20}D$ 1.4788 and $d^{24}D$ (10 cm.) −18.53°. The main portion of 251 g. 2,4-dimethylphenol (m. p. 23–24°) mixed with 324 g. of *l*-nopinene was stirred and cooled in ice–concd. hydrochloric acid while 1.6 g. of boron trifluoride–ether catalyst, dissolved in the remainder of the 2,4-dimethylphenol, was added during a period of an hour. After another hour the flask was stoppered and left overnight in a 5° refrigerator. The reaction mixture contained 213 g. of unreacted 2,4-dimethylphenol (removed by base-extraction) and 262 g. nopinene. The main portion of the nopinene had $n^{20}D$ 1.4774 and $\alpha^{24}D$ −21.88° (10-cm. tube); lowered refractive index and increased rotation indicated that about 10% of the nopinene had isomerized to *l*-α-pinene, which has $n^{20}D$ 1.4652 and $\alpha^{25}D$ (2 dm.) −80.75°.[5] The remainder of the reaction mixture, after distillation of a 12-g. forerun, yielded two fractions of colorless liquid having identical rotations: (1) 18 g. of b. p. 175.5–181.5° (10 mm.); $n^{20}D$ 1.5245; $\alpha^{23}D$ (10 cm.) −40.0°; (2) 41.0 g. of b. p. 181.5–184° (10 mm.); $n^{20}D$ 1.5264; $\alpha^{23}D$ (10 cm.) −39.9°. A 15-g. residue remained in the still-pot. The fractions, which may have contained bornyl 2,4-dimethylphenyl ether, did not crystallize.

Rearrangement of Bornyl 2,4-Dimethylphenyl Ether.—The above fractions of α_D −40° were combined and subjected to the rearrangement reaction (55 g. in 82 ml. of

---

[5] R. E. Fuguitt and J. E. Hawkins, THIS JOURNAL, **69**, 319 (1947).

benzene with 0.5 g. of boron trifluoride–ether catalyst for five and one-half hours at 88.5°). Products include 1 g. of monocyclic terpenes, n^{20}_{D} 1.4798; 16 g. of b. p. 171–176° (10 mm.), n^{20}_{D} 1.5217–1.5244 and α^{25}_{D} −10 to −16°, apparently monocyclic terpene ethers of 2,4-dimethylphenol; and 19 g. of higher boiling material and resin.

In another experiment boron trifluoride–ether catalyst was added to an ice–concd. hydrochloric acid-cooled mixture of 816 g. nopinene and 632 g. 2,4-dimethylphenol. On the addition of the seventh ml. of catalyst (four hours after beginning of catalyst addition) vigorous exothermic reaction suddenly took place; in three minutes the temperature rose from −1 to 140°. Ten minutes later the reaction was stopped by addition of 10% sodium hydroxide; the mixture had cooled to 57°. Petroleum ether was added to facilitate handling; unreacted 2,4-dimethylphenol (455 g.) was removed by extraction with aqueous alkali; the solvent and terpenes (39 g.) were removed by distillation with a short stripping column; and the reaction products were then distilled to give a 708-g. fraction, b. p. 185–220° (20 mm.), leaving 335 g. (41%) of nopinene polymer, a brittle brown resin. The distillate was fractionated through a 39 in. × 34 mm. spiral screen column[6,7] having a 50 × 50 mesh stainless steel screen packing spiraled about a 17 mm. inner glass tube and having an efficiency of 29 theoretical plates. The physical properties of the products indicated them to include about 10% terpene dimer (b. p. 156–165° (10 mm.), n^{20}_{D} 1.5121, α^{24}_{D} (10 cm.) +20.2°), 50% terpene ethers of 2,4-dimethylphenol (b. p. 172–174.5° (10 mm.), n^{20}_{D} 1.5236–1.5248, α^{24}_{D} (10 cm.) −12.0 to −20.7°) and 30% 2,4-dimethyl-6-isobornylphenol (b. p. 186–198° (10 mm.), n^{20}_{D} 1.5375–1.5412, α^{24}_{D} (10 cm.) +0.8 to +2.1°), a highly viscous liquid which crystallized on cooling. Recrystallized from petroleum ether, the last fraction had m. p. 79.6–80.6°; 2,4-dimethyl-6-isobornylphenol from camphene, m. p. 82.8–83.4°; m. p., mixed, 80.0–82.0°.

Alkylation of 2,4-Dimethylphenol with Dipentene.—A mixture of 408 g. of dipentene and 366 g. of 2,4-dimethylphenol (m. p. 18–20.5°) was stirred at 60–82° for six and one-half hours. Nine grams of boron trifluoride–ether catalyst was added slowly during the first four hours, after which heat was applied to keep the temperature up. The reaction mixture, worked up in the manner described for the previous experiments, yielded 191 g. (25%) of terpene ethers of 2,4-dimethylphenol having n^{24}_{D} 1.5250–1.5261 and b. p. 169–176° (10 mm.), instead of the nuclear alkylation expected as the main product because of the tertiary olefin structure of dipentene.

The position of the isobornyl group in 2-isobornylphenol and the ether nature of several reaction products of nopinene and dipentene with 2,4-dimethylphenol were confirmed by infrared absorption spectra. The infrared data will be reported in a forthcoming paper.

Summary

Phenols condense with camphene at 0° with acid catalyst present to yield isobornyl ethers in good yield. The ethers rearrange at elevated temperatures, also in the presence of acid catalysts, to yield nuclearly substituted phenols. In the case of 2,4-dimethylphenol, where the number of rearrangement products is limited, the crystalline terpene phenol can be obtained in good yield. Nopinene reacts less smoothly with 2,4-dimethylphenol to give terpene ethers at 0° and ethers, along with some 2,4-dimethyl-6-isobornylphenol at elevated temperature. Dipentene yielded terpene ethers of 2,4-dimethylphenol instead of expected nuclear alkylation.

AKRON 17, OHIO RECEIVED MAY 10, 1948

---

[6] H. S. Lecky and R. H. Ewell, *Ind. Eng. Chem., Anal. Ed.*, **12**, 544 (1940).

[7] W. D. Stallcup, R. E. Fuguitt and J. E. Hawkins, *Ind. Eng. Chem., Anal. Ed.*, **14**, 503 (1942).

[CONTRIBUTION FROM THE DEPARTMENT OF RESEARCH IN PURE CHEMISTRY, MELLON INSTITUTE]

Presence of D-(*levo*)-2,3-Butanediol in the Mixed 2,3-Butanediols Produced by Normal Fermentation of Glucose with *Aerobacter aerogenes*

BY R. STUART TIPSON

In the course of certain investigations in progress in this laboratory, it became desirable to obtain pure samples of the L-(*dextro*)[1]- and *meso*-isomers of 2,3-butanediol, respectively. The pure *dextro*-form is not commercially available but a mixture ($[\alpha]^{25}_{\mathrm{D}}$ about +1.0°) supposedly consisting of the *meso*-form (about 90%) with the *dextro*-form (about 10%) is produced by the action of *Aerobacter aerogenes* on sucrose[2] or glucose.[3] It is said that the isomers may be separated from this mixture by fractional distillation[4] at atmospheric pressure, but, since the boiling points of the two diols differ by only 3 to 4°, this is presumably a rather tedious and unsatisfactory procedure, as evidenced by the specific rotations recorded by various authors, *viz.*, +5.0[5]; +2.41 (further purified,[6] +6.9); +10.15 (after fermentation of the *meso*-diol with *Acetobacter suboxydans*[7]); +13.0°.[8]

Having successfully used[9] the procedure of conversion to the isopropylidene derivatives, followed by fractional distillation, for the separation of mixtures of three closely related monosaccharides, it occurred to us that separation of the *dextro*- from the *meso*-diol might be achieved in the same manner. Consequently, the mixed diols were condensed with acetone in the presence of concentrated sulfuric acid; in some experiments, anhydrous copper sulfate was added as desiccant for the water liberated during the reaction.[9,10] On

---

[1] Morell and Auernheimer, THIS JOURNAL, **66**, 792 (1944).

[2] Fulmer, Christensen and Kendall, *Ind. Eng. Chem.*, **25**, 798 (1933).

[3] Lees, Fulmer and Underkofler, *Iowa State Coll. J. Sci.*, **18**, 359 (1944).

[4] Ward, Pettijohn, Lockwood and Coghill, THIS JOURNAL, **66**, 541 (1944).

[5] Böeseken and Cohen, *Rec. trav. chim.*, **47**, 839 (1928).

[6] Chappell, *Iowa State Coll. J. Sci.*, **11**, 45 (1936).

[7] Fulmer, Underkofler and Bantz, THIS JOURNAL, **65**, 1425 (1943).

[8] Knowlton, Schieltz and Macmillan, *ibid.*, **68**, 208 (1946).

[9] Levene and Tipson, *J. Biol. Chem.*, **115**, 731 (1936).

[10] Levene and Tipson, *ibid.*, **106**, 113 (1934); Tipson and Cretcher, *J. Org. Chem.*, **8**, 95 (1943).