o-Toluic acid:

$$\log_{10} K = 3.533 - 1836/T \quad (\pm 0.3\%)$$
$$\Delta H = 8400 \pm 200 \text{ calories}$$

m-Toluic acid:

$$\log_{10} K = 4.056 - 2063/T \quad (\pm 0.3\%)$$
$$\Delta H = 9440 \pm 200 \text{ calories}$$

Discussion.—It will be observed from Table I and Fig. 1 that at a given temperature, *o*-toluic acid has a substantially larger value for K than either of the other two acids. This is very likely due to steric effects since methyl substituents in the *ortho* position would be expected to make dimerization more difficult. *m*-Toluic acid and benzoic acid appear to associate approximately to the same extent.

The values of A and B which appear in equation (3) cannot be determined very accurately even though the values of $\log_{10} K$ are known much better. The reason for this is that the temperature range is so small that errors in A and B can easily compensate for each other. As a result the values for ΔH are much less certain than those for $\log_{10} K$. It is also possible to calculate entropies of dissociation from the values of A, but this has not been done since they would be even less accurate (on a percentage basis) than values for ΔH.

Although the probable errors in $\log_{10} K$ are not large, the corresponding errors in K are of course larger. The equation given above for benzoic acid differs somewhat from that of Wall and Rouse[3] although the actual dissociation constants which were found by the two separate investigations are not very different. The results given above are believed to be more accurate than the earlier ones.

Summary

The associations of benzoic, *o*-toluic and *m*-toluic acids in benzene solution have been studied by a method involving the indirect measurement of vapor pressure lowerings. Phenanthrene was used as a standard unassociated substance and Raoult's law was assumed to be valid. Benzoic and *m*-toluic acids are found to associate to approximately the same extent but *o*-toluic acid associates appreciably less than the other two at a given temperature. The heats of dissociation of the acid dimers have also been determined and found to be in the neighborhood of 9000 calories, with *o*-toluic acid showing the lowest value and *m*-toluic acid the highest.

URBANA, ILLINOIS RECEIVED DECEMBER 21, 1944

[CONTRIBUTION FROM THE KEDZIE CHEMICAL LABORATORY, MICHIGAN STATE COLLEGE]

Condensation of Secondary Alcohols with Phenol in the Presence of Aluminum Chloride

BY R. C. HUSTON, R. L. GUILE, D. L. BAILEY, R. J. CURTIS AND M. T. ESTERDAHL

Previous contributions from this Laboratory have described the condensation of tertiary aliphatic alcohols with phenol[1] and benzene[2] using aluminum chloride as the condensing reagent.

Secondary alcohols have also been shown to condense with benzene[3] under the influence of the same catalyst to give in general mixtures of secondary alkylbenzenes, tertiary alkylbenzenes or mixtures of secondary and tertiary alkylbenzenes. Condensation without rearrangement took place only in the case of 2-propanol, 2-butanol, and 3,3-dimethyl-2-butanol.

As an extension of this work, the secondary alcohols, up to and including the secondary hexyl alcohols, have been condensed with phenol.

Separable mixtures of 2-*p*-hydroxyphenylpentane and 3-*p*-hydroxyphenylpentane were formed by the condensation of 2-pentanol and of 3-pentanol with phenol. The structures of these alkylphenols were established by conversion of corresponding alkylbenzenes[3] to their *p*-hydroxy derivatives by nitration, reduction, diazotization and hydrolysis. The melting point and mixed melting point determination of the α-naphthylurethans indicated that 3-pentanol yielded approximately equal quantities of the two isomers while 2-pentanol gave mostly 2-*p*-hydroxyphenylpentane.

2-Hexanol and 3-hexanol condensed with phenol to form mixtures of alkylphenols which could not be separated because of high viscosity, closeness of boiling points and like solubility. The α-naphthylurethans could not be crystallized to sharp melting points. These same alcohols, when condensed with benzene,[3] gave mixtures which could not be separated. Melting points of the α-naphthylurethans indicate that mixtures from both 2-hexanol and 3-hexanol contain, as the main product, 3-*p*-hydroxyphenylhexane with smaller amounts of 2-*p*-hydroxyphenylhexane.

The theory predicts the possible formation of three alkylphenols from 2-methyl-4-pentanol. Of these, 2-methyl-4-*p*-hydroxyphenylpentane and 2-methyl-2-*p*-hydroxyphenylpentane are known. Attempts to prepare 2-methyl-3-phenylpentane by the modified[3] Klages method[4] were not successful because of the failure to obtain complete reduction of the dehydration product of 2-methyl-3-phenyl-3-pentanol by means of sodium. Attempts to hydrogenate by means of zinc and hydro-

---

[1] R. C. Huston and C. R. Meloy, THIS JOURNAL, **64**, 2655 (1942).

[2] R. C. Huston and J. Awuapara, *J. Org. Chem.*, **9**, 401 (1944).

[3] R. C. Huston and I. A. Kaye, THIS JOURNAL, **64**, 1576 (1942).

[4] A. Klages, *Ber.*, **36**, 622 (1903); **37**, 1447, 1721 (1904).

chloric acid or by platinum catalyst[5] also failed. Results were equally unsatisfactory when these methods were applied to the dehydration product of 2-methyl-3-*p*-methoxy-3-pentanol. Both compounds were, however, completely hydrogenated in the presence of palladium.

The condensation product of 2-methyl-4-pentanol with phenol gave a mixture of isomeric α-naphthylurethans. The melting range of this mixture (120.5–123.4)[6] is well above the melting point of the α-naphthylurethan of 2-methyl-4-*p*-hydroxyphenylpentane (107°), below that of 2-methyl-2-*p*-hydroxyphenylpentane (128°) and near that of 2-methyl-3-*p*-hydroxyphenylpentane (124°). Repeated distillation of the condensate indicated that it was made up of 2-methyl-2-*p*-hydroxyphenylpentane with relatively small amounts of 2-methyl-4-*p*-hydroxyphenylpentane and 2-methyl-3-*p*-hydroxyphenylpentane.

The formation of 2,3-dimethyl-2-*p*-hydroxyphenylbutane when 2,2-dimethyl-3-butanol is condensed with phenol involves the migration of a methyl group and the formation of a tertiary alkyl cation as an intermediate. Earlier work[3] has shown that condensation of this alcohol with benzene at the same or lower temperatures gives 2,2-dimethyl-3-phenylbutane with no evidence of rearrangement.

As in the condensation of secondary alcohols with benzene,[2,3] the most satisfactory explanation of the condensation of secondary alcohols with phenols is that the aluminum chloride forms an addition complex with the alcohols by a dative bond between the aluminum and the hydroxyl oxygen. This complex, unlike those from tertiary alcohols, decomposes directly or through the aluminate, forming an alkene. The alkene, under the influence of aluminum chloride, then condenses with phenol. In the case of 2-methyl-4-pentanol, it is apparent that a shift of the double bond occurs before the main condensation takes place.

It is suggested that a possible explanation of the shift of a methyl group when 2,2-dimethyl-3-butanol condenses with phenol may be found in the weak attraction of the tertiary butyl group for its connecting pair. The electrophilic attraction of the carbon attached to the hydroxyl would be decreased and the formation of the cation $(CH_3)_3CCH^+—CH_3$ would be made possible. This would then rearrange to the thermodynamically more stable tertiary cation $(CH_3)_2C^+—CH(CH_3)_2$ which condenses with phenol. The failure of 2,2-dimethyl-3-butanol to undergo rearrangement when it is condensed with benzene[3] makes a more detailed study necessary.

Experimental

Condensation of Secondary Alcohols with Phenol.—This is a modification of methods used in the condensation of tertiary alcohols[1] with phenol.

Quarter mole quantities of alcohol and half mole quantities of phenol were used. During the two-hour addition period of aluminum chloride (0.18 mole), the flask was cooled in a water-bath if the temperature exceeded 35°.

The color of the reaction mixture changed from a light yellow to a brilliant red as the aluminum chloride was added, some hydrogen chloride was given off and the viscosity of the solution increased. The reaction mixture was stirred for four hours after the aluminum chloride was added and it was during this period that large volumes of hydrochloric acid were evolved. The flask was warmed in a water-bath (50–60°) if the solution became viscous enough to hinder stirring. Condensations of 2-propanol and 2-butanol were carried out at 80°.

Each reaction yielded a small amount of uncondensed alcohol, traces of its chloride and a small amount of tarry residue (2 to 4 g.). Crystalline products were separated from oily impurities by porous plate treatment and recrystallized from petroleum ether or a 50% mixture of alcohol and petroleum ether.

Condensation of 2-Methyl-4-pentanol with Phenol.—The main product was collected in 55% yield at 105–120° (3 mm.). This gave a mixture of α-naphthylurethans melting at 120.5–123.5°. After repeated fractionation about 90% of the crude product came over at 110–113° (2 mm.). This solidified when cooled and after pressing on a porous plate it was recrystallized from petroleum ether. It was identified by its melting point (36–37°) and the melting points of its α-naphthylurethan and 3,4-dinitrobenzoyl ester (120–121°) as 2-methyl-2-*p*-hydroxyphenylpentane.[7] A mixed melting point determination using the 3,5-dinitrobenzoyl ester and the 3,5-dinitrobenzoyl ester of 2-methyl-3-*p*-hydroxyphenylpentane gave a marked depression. The phenolic fraction which came over just below 110° (2 mm.) did not give solid derivatives.

Synthesis of 2-Methyl-3-phenylpentane.—Phenyl isopropyl ketone was prepared from isobutyryl chloride and benzene by the Friedel and Crafts reaction. It was identified by the melting point of its phenylhydrazone. The ketone, in ether, was added dropwise to a molecular equivalent of ethylmagnesium bromide at 10°. Hydrolysis gave 2-methyl-3-phenyl-3-pentanol which was collected at 106–112° (8 mm.).

The alcohol was dehydrated by refluxing in a Stark and Dean moisture trap[8] for one hour and the product collected at 83–84° (14 mm.). It consisted of 2-methyl-3-phenyl-2-pentene with some 2-methyl-3-phenyl-3-pentene and was characterized by the following physical constants: b. p. (745 mm.) 206–208°; d^{20}_4 0.8870; n^{20}_D 1.5104; γ^{20} 32.2. Hydrogenation in the presence of palladium as a catalyst[9] gave 2-methyl-3-phenylpentane quantitatively: b. p. (745 mm.) 207–209°; d^{20}_4 0.8678; n^{20}_D 1.4912; γ^{20} 30.96.

Anal. Calcd. for $C_{12}H_{18}$: C, 88.89; H, 11.11; *MR*, 54.05; P, 441.1. Found: C, 88.79; H, 11.42; *MR*, 54.08; P, 440.4.

Synthesis of 2-Methyl-3-*p*-hydroxyphenylpentane.—Isopropyl *p*-methoxyphenyl ketone was prepared by a modification of the method used by Auwers.[10] One mole of isobutyryl chloride, in 500 cc. of petroleum ether, was added to one and a quarter moles of anisole. One mole of aluminum chloride was added to the stirred mixture over a period of two hours while the temperature was maintained at 10°. Decomposition of the deep red viscous intermediate gave 2-methyl-3-*p*-methoxyphenylpentane boiling at 129–131° (3 mm.); yield, 62%. The ketone was also prepared by the addition of an ether solution of *p*-methoxyphenylmagnesium chloride to isobutyryl chloride but the yield was poor.

Addition of the ketone to an ether solution of ethylmagnesium bromide gave the very unstable 2-methyl-3-*p*-methoxyphenyl-3-pentanol, which was dehydrated in a Stark and Dean moisture trap. The unsaturated product

---

(5) W. F. Bruce, THIS JOURNAL, **58**, 687 (1936).

(6) Approximately the same melting range was obtained when 2-methyl-4-pentanol was condensed with benzene and the alkyl benzene mixture converted to phenols.[3]

(7) R. C. Huston and T. Y. Hsieh, THIS JOURNAL, **58**, 439 (1936).

(8) E. W. Dean and D. D. Stark, *Ind. Eng. Chem.*, **12**, 486 (1920).

(9) R. L. Shriner and R. Adams, THIS JOURNAL, **47**, 1683 (1925).

(10) K. V. Auwers, *Ann.*, **408**, 250 (1915).

TABLE I

Alcohol condensed	Products	Yield, %	B. p., °C. at 745 mm.
2-Propanol	2-*p*-Hydroxyphenylpropane	5	228–229
2-Butanol	2-*p*-Hydroxyphenylbutane	4	239–240
2-Pentanol	2-*p*-Hydroxyphenylpentane*[3,a,c] and 3-*p*-Hydroxyphenylpentane[a,d]	37	240–250 90– 95 (3 mm.)
3-Pentanol	2-*p*-Hydroxyphenylpentane, and 3-*p*-Hydroxyphenylpentane	36	See above
2-Methyl-3-butanol	2-Methyl-2-*p*-hydroxyphenylbutane[7]	66	112–120 (3 mm.)
2-Hexanol	Mixture of hexylphenols[b,e]	23	251–255
3-Hexanol	Mixture of hexylphenols[b,f]	26	252–256
2-Methyl-3-pentanol	2-Methyl-2-*p*-hydroxyphenylpentane[7]	54	125–128 (4 mm.)
2-Methyl-4-pentanol	Mixture of hexylphenols[b,g]	55	249–259
3-Methyl-2-pentanol	3-Methyl-3-*p*-hydroxyphenylpentane[7]	59	124–127
2,2-Dimethyl-3-butanol	2,3-Dimethyl-2-*p*-hydroxyphenylbutane[7]	55	122–125 (4 mm.)

* Corrected m. p. 85–86°. See U. S. Patent 2,104,412 (1938). [a] Calcd. for $C_{11}H_{16}O$ for *c* and *d:* C, 80.49; H, 9.76; mol. wt. 164.24. [b] Calcd. for $C_{12}H_{18}O$ for *e, f, g:* C, 80.85; H, .10.1; mol. wt., 178.6. [c] Found: C, 80.74; H, 9.79; mol. wt., 164.2. [d] Found: C, 80.15; H, 9.98; mol. wt., 164.7. [e] Found: C, 80.82; H, 10.20; mol. wt., 178. [f] Found: C, 80.62; H, 10.21; mol. wt., 177.3. [g] Found: C, 80.51; H, 10.24; mol. wt., 177.9.

TABLE II

α NAPHTHYLURETHANS OF *p*-ALKYLPHENOLS

Parent compound	M. p., °C.	% N (Calcd.: N, 4.03)
2-*p*-Hydroxyphenylpropane	71 (benzoic ester)	
2-*p*-Hydroxyphenylbutane	103 –104	
2-*p*-Hydroxyphenylpentane[3]	99 –100	
3-*p*-Hydroxyphenylpentane[3]	114 –115	
2-Methyl-2-*p*-hydroxyphenylbutane[7]	125 –126	
2-*p*-Hydroxyphenylhexane[3]	108 –109	
3-*p*-Hydroxyphenylhexane[3]	94 – 95	
Hexylphenols from 2-hexanol	94 – 97	4.12
Hexylphenols from 3-hexanol	93 – 95	4.06
2-Methyl-2-*p*-hydroxyphenylpentane[6]	127 –128	4.05
2-Methyl-3-*p*-hydroxyphenylpentane	124 –124.5	4.02
2-Methyl-4-*p*-hydroxyphenylpentane[3]	106 –107	
Hexylphenols from 2-methyl-4-pentanol	120.3–123.5	4.14
3-Methyl-3-*p*-hydroxyphenylpentane[6]	147 –148	4.02
2,3-Dimethyl-2-*p*-hydroxyphenylbutane[6]	115 –116	4.00

which could not be reduced by means of sodium and alcohol,[4] consisted of 2-methyl-3-*p*-methoxyphenyl-2-pentene[11] with some 2-methyl-3-*p*-methoxyphenyl-3-pentene: b. p. (12 mm.) 122–124°; b. p. (739 mm.) 244–247; $d^{20}{}_4$ 0.9450; $n^{20}{}_D$ 1.5195; γ^{20} 34.82.

Anal. Calcd. for $C_{13}H_{18}O$: C, 81.25; H, 10.42. Found: C, 81.02; H, 10.52.

The unsaturated product was dissolved in alcohol and reduced by means of palladium[7] to 2-methyl-3-*p*-methoxyphenylpentane: b. p. (3 mm.) 98–99°; b. p. (739 mm.) 245–247°; $d^{20}{}_4$ 0.9281; $n^{20}{}_D$ 1.5008; γ^{20} 33.79. *Anal.* Calcd. for $C_{13}H_{20}O$: C, 81.25; H, 10.42; *MR*, 60.43; P, 500.1. Found: C, 81.02; H, 10.52; *MR*, 60.99; P, 498.8.

Demethylation was accomplished by refluxing 10 g. of the ether with 50 g. of phenol and 100 ml. of 48% hydrobromic acid for four hours.[12] Dilution with water and extraction with ether gave 2-methyl-3-*p*-hydroxyphenylpentane; b. p. 108–110°; m. p. 33–35°. *Anal.* Calcd. for $C_{12}H_{18}O$: C, 80.90; H, 10.11. Found: C, 80.81; H, 10.18. 3,5-Dinitrobenzoyl ester: m. p. 118–119°.

2-Methyl-3-*p*-hydroxyphenylpentane was also prepared from 2-methyl-3-phenylpentane by nitration, reduction diazotization and hydrolysis. The nitro compound (b. p. 130–140°) was reduced by means of platinum catalyst.[13] The amine boiled at 101–103° (3 mm.). *Anal.* Calcd. for $C_{12}H_{19}N$: N, 7.84. Found: N, 7.91.

It was acylated to 2-methyl-3-*p*-acetaminophenylpentane; m. p. 134°. *Anal.* Calcd. for $C_{14}H_{21}ON$: N, 6.39. Found: N, 6.41.

Because of the insolubility of the sulfate of the amine, the usual technique of diazotization was modified. Four grams of 2-methyl-3-*p*-aminophenylpentane was stirred into 20 ml. of water to which had been added 3 ml. of concentrated sulfuric acid. The salt which separated was partially dissolved by adding 20 ml. of alcohol. The mixture was cooled to 0°, and a 25% solution of sodium nitrite was added dropwise with stirring until the theoretical amount had been added. Stirring was continued until most of the sulfate dissolved and a solution of 0.5 g. of urea was slowly added. The solution was poured into ten volumes of water and heated on the water-bath for two hours. After extraction with ether and evaporation of the solvent, the crude phenol was distilled with steam and again extracted with ether. Distillation of the residue from this extract gave 2-methyl-3-*p*-hydroxyphenylpentane, which was collected at 105–110° (3 mm.) and identified by the melting point of its α-naphthylurethan.

Summary

1. A technique was developed for the condensation of secondary alcohols with phenol in the presence of aluminum chloride.

2. 2-Propanol and 2-butanol gave small yields of the *p*-secondary alkylphenols.

3. The unbranched secondary pentyl and hexyl alcohols gave mixtures of secondary alkylphenols.

4. The branched alcohols, 2-methyl-3-butanol, 2-methyl-3-pentanol and 3-methyl-2-pentanol gave excellent yields of *p*-*t*-alkylphenols.

5. A mixture of hexylphenols resulted from the condensation of 2-methyl-4-pentanol, the principal constituent of which was 2-methyl-2-*p*-hydroxyphenylpentane.

6. The migration of a methyl group during the condensation of 2,2-dimethyl-3-butanol gave 2,3-dimethyl-2-*p*-hydroxyphenylbutane.

EAST LANSING, MICH. RECEIVED SEPTEMBER 11, 1944

---

(11) Demethylation, after attempts to reduce with sodium and alcohol, resulted in a mixture of polymers which had molecular weights averaging 1200 to 1400.

(12) L. H. Welsh and N. L. Drake, THIS JOURNAL, **60**, 59 (1938).

(13) R. Adams, F. L. Cohen and O. W. Rees, *ibid.*, **49**, 1093 (1927).