

[COMMUNICATION FROM THE LABORATORY OF ORGANIC CHEMISTRY, UNIVERSITY OF WISCONSIN]

### The Catalytic Hydrogenation of Esters to Alcohols. III

BY HOMER ADKINS, BRUNO WOJCIK AND LLOYD W. COVERT

A limitation upon the catalytic hydrogenation of esters to alcohols<sup>1</sup> appeared to be the labilizing effect of carbinol, carbalkoxy and phenyl groups for the cleavage of the carbon to oxygen linkage in the alcohol.<sup>2,3</sup> For example, ethyl phenylacetate was hydrogenated to ethylbenzene as well as to  $\beta$ -phenylethyl alcohol, *i. e.*,  $C_6H_5CH_2CO_2C_2H_5 \rightarrow C_6H_5CH_2CH_2OH \rightarrow C_6H_5C_2H_5 + H_2O$ . It thus seemed desirable to direct attention toward modifications of the catalyst and of the conditions of hydrogenation which might minimize the hydrogenation of the carbalkoxy to a methyl group without decreasing the rate of conversion to a carbinol. This first objective has been sought in the further study of the hydrogenation of ethyl phenylacetate.

A comparison of catalysts and other factors in the hydrogenation of ethyl phenylacetate is a complicated matter because of the number of variables involved. At least five substances may sometimes be found in the product of hydrogenation, *i. e.*, unchanged ethyl phenylacetate, phenylacetic acid,  $\beta$ -phenylethyl alcohol, ethylbenzene and the  $\beta$ -phenylethyl ester of phenylacetic acid. The alcohol and hydrocarbon are the result of hydrogenation, the ethyl phenylacetate of incomplete hydrogenation, the  $\beta$ -phenylethyl phenylacetate of alcoholysis, and the acid of hydrolysis. In addition to these reactions there may occur reduction of the catalyst from the black or active state to the red or relatively inactive state.

Folkers observed that the rate of hydrogenation, the proportion of products and the stability of the catalyst varied with different samples of ethyl phenylacetate. He was able to prepare from phenylacetyl chloride and ethanol samples of the ester which after careful fractionation could be hydrogenated rapidly and completely. In contrast to this was the observation that the ester obtained by the alcoholysis of benzyl cyanide (either from a commercial source or prepared in this Laboratory) was especially deleterious in its effect upon the catalyst.

It has now been found that pure ethyl phenylacetate may be readily prepared by heating the commercial product with catalytic nickel under hydrogen (3 hrs., 175°, 100 atm.) and then distilling the product. This process results in the elimination of any halogen or nitrogen containing impurities. The chief impurity is apparently benzyl cyanide which is eliminated in part as *N*-di- $\beta$ -phenylethyl phenylacetamide, ( $C_6H_5CON-$

(1) Adkins and Folkers, *THIS JOURNAL*, **53**, 1095 (1931).

(2) Folkers and Adkins, *ibid.*, **54**, 1145 (1932).

(3) Connor and Adkins, *ibid.*, **55**, 4678 (1933).

$(\text{CH}_2\text{CH}_2\text{C}_6\text{H}_5)_2$ ).<sup>4</sup> Di- $\beta$ -phenylethylamine was no doubt produced from the cyanide.<sup>5</sup> This compound then reacted with ethyl phenylacetate to give the substituted amide. Phenylacetamide was also formed, as would be expected, since ammonia as well as di- $\beta$ -phenylethylamine is produced by the hydrogenation of benzyl cyanide. The amounts of the amides obtained indicated that the original sample of the ester contained approximately 1% of benzyl cyanide.

It is obvious that a complete study of the hydrogenation of ethyl phenylacetate would be so extensive as to be of doubtful value in consideration of the magnitude of the work involved. The present study was primarily devoted toward ascertaining whether the ratio of alcohol to hydrocarbon could be increased by modification of the copper-chromium oxide catalyst.<sup>6</sup> As a result of a long series of experiments which need not be described in detail, this question must be answered in the negative. It appears that the ratio of  $\beta$ -phenylethyl alcohol to ethylbenzene is dependent upon the completeness of hydrogenation of the ester. That is to say the more completely the ester is hydrogenated the lower the amount of  $\beta$ -phenylethyl alcohol in proportion to the amount of ethylbenzene. This result is exactly what one would expect if the ratio of products is dependent only upon the relative concentration of the ester and the alcohol in the mixture undergoing hydrogenation. It means that none of the modifications of the catalyst effected a preferential action upon the hydrogenation of the carbethoxy as compared with the carbinol group. The best yields of  $\beta$ -phenylethyl alcohol from ethyl phenylacetate will thus be obtained if the hydrogenation is interrupted prior to the completion of the hydrogenation of the ester. In practice the best yields were obtained if the hydrogenations were stopped when there was 5 to 10% of residual ester. Under these circumstances the yields of alcohol were approximately 60% based upon the amount of ester submitted to hydrogenation, and the time of hydrogenation was less than an hour. Yields as high as 80% of alcohol based upon the amount of ester hydrogenated were obtained by interrupting the hydrogenation at earlier stages.

Many things have been shown to lower the optimum yields of alcohol referred to in the preceding paragraph: *i. e.*, a large amount of methanol (40%), or a small amount of cyanides, amines, ammonia, or acids in the reaction mixture; incomplete decomposition or washing of the catalyst resulting in the introduction of nitrogenous material into the reaction mixture; and deficiency in amount or activity of catalyst. All of these

(4) M. p. 143.5°. *Anal.* Calcd. for  $\text{C}_{14}\text{H}_{19}\text{NO}$ : N, 4.25. Found: N, 4.17. The compound was hydrolyzed and the corresponding amine hydrochloride and acid identified by mixed melting point with authentic specimens. The substituted amide has recently been obtained in 50% of the theoretical yield by subjecting a mixture of benzyl cyanide and ethyl phenylacetate to the conditions used for the purification of the ester.

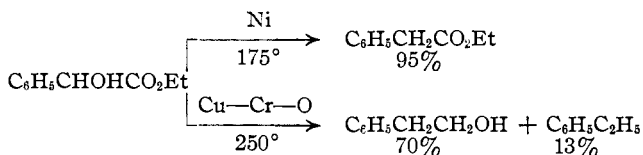
(5) *Cf.* Winans and Adkins, *THIS JOURNAL*, **54**, 307 (1932).

(6) Such a selective activation of nickel for the hydrogenation of benzyl alcohol and of furfural acetal has recently been described. Covert, Connor and Adkins, *THIS JOURNAL*, **54**, 1655 (1932).

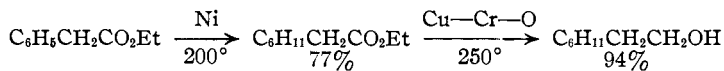
changes in conditions of hydrogenation resulted in a lower ratio of alcohol to hydrocarbon, *i. e.*, in a selective deactivation of the catalyst.

A second objective in this investigation was to increase the available information in regard to the effect of phenyl and cyclohexyl groups in various esters upon the ratio of products resulting from hydrogenation. To this end a number of esters containing one or the other of these groups were submitted to hydrogenation over copper-chromium oxide or nickel catalysts. A summary of the results is given below, the yields of various products being indicated.

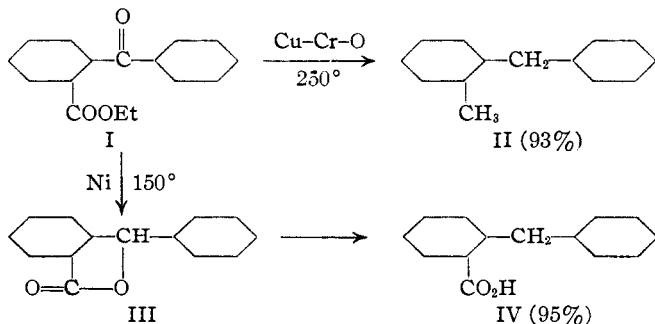
Ethyl mandelate was hydrogenated to ethyl phenylacetate over nickel and over copper-chromium oxide to  $\beta$ -phenylethyl alcohol accompanied by some ethylbenzene. In the latter case the ratio of alcohol to hydrocarbon was higher than when ethyl phenylacetate was subjected to hydrogenation.



Ethyl phenylacetate was hydrogenated over nickel to ethyl cyclohexylacetate and this in turn over copper chromium oxide to  $\beta$ -cyclohexylethyl alcohol.



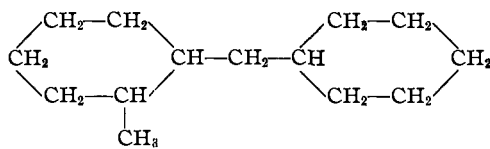
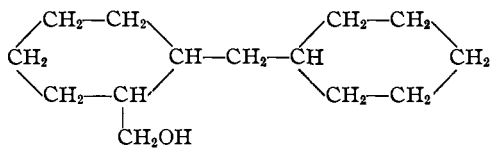
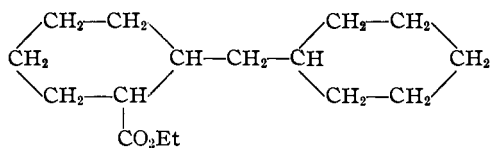
Ethyl *o*-benzoylbenzoate (I) was readily and almost quantitatively converted into either of two products depending upon the conditions adopted. (1) At 250° with the copper-chromium oxide catalyst the only product was *o*-benzyltoluene (II), the carboxyl having been converted into a methyl group.



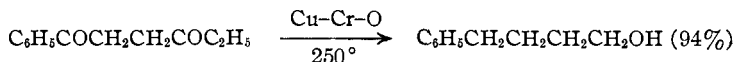
In alcohol, with nickel at 150° the ketone group was converted into a carbinol, the latter reacted with the carboxy group with the elimination of water and the formation of a lactone (III) which then underwent hy-

drogenolysis to *o*-benzylbenzoic acid (IV). The acid was *not* formed through hydrolysis, for the cleavage occurred quantitatively in an alcoholic solution under conditions in which hydrolysis of the ester would occur to a very small extent.

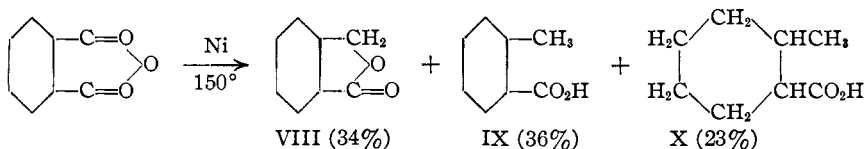
The ester of *o*-benzylbenzoic acid was smoothly hydrogenated over nickel at 150° to ethyl *o*-hexahydrobenzyl hexahydrobenzoate (V). This ester over copper–chromium oxide at 250° was hydrogenated to the corresponding carbinol (VI) accompanied by a small amount of the hydrocarbon (VII).



The relative magnitudes of the effects of the phenyl group in the 1 and in the 4 positions with respect to a carbon to oxygen linkage is well illustrated by the ease and completeness of the hydrogenation of ethyl  $\beta$ -benzoylpropionate to 4-phenylbutanol-1.

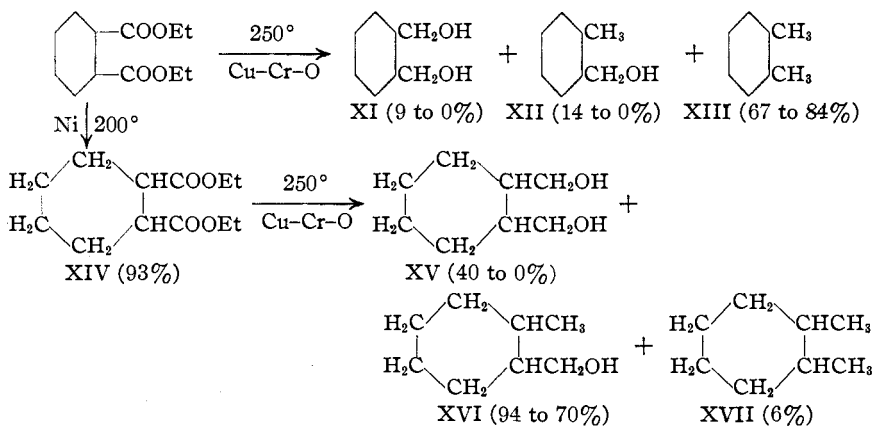


When phthalic anhydride was hydrogenated over nickel at 150° the first hydrogenation product was apparently phthalide (VIII).<sup>7</sup> There was also produced *o*-toluic acid (IX) and the corresponding hydrogenated compound, 2-methylhexahydrobenzoic acid (X).

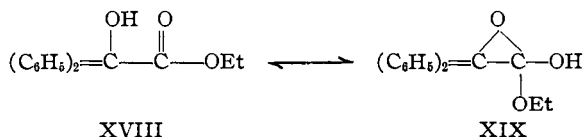


(7) Cf. Eykman, *Chem. Weekblad*, 4, 191 (1907).

The hydrogenation of diethyl phthalate over copper-chromium oxide catalyst gave a mixture of three products, *i. e.*, phthalyl alcohol (XI), *o*-methylbenzyl alcohol (XII), and *o*-xylene (XIII). Over nickel the hydrogenation of diethyl phthalate proceeded smoothly to diethyl hexahydrophthalate (XIV). This last ester, like diethyl phthalate, gave three products when subjected to the action of hydrogen in the presence of the copper-chromium oxide catalyst at 250°. These three compounds were the hexahydro derivatives of those obtained from diethyl phthalate (XV-XVII). However, it is important to note that while the hydrocarbon was the chief product from the phenyl ester, the glycol and alcohol were the chief products from the cyclohexyl ester.



The hydrogenation of benzilic ester gave unexpected results, for this ester was rather rapidly hydrogenated at 125°, a temperature about 100° lower than that required for other esters, and the glycol (1,1-diphenylethanediol-1,2) was obtained in a good yield (77%) despite the fact that one hydroxy group is but one carbon atom distant from a benzenoid ring, a position which renders it very labile toward hydrogenation. The low temperature required for the hydrogenation of the benzilic ester (XVIII) suggests that the hydrogenation proceeded through a tautomer (XIX), the hemiacetal of an oxido ketone (XIX).



Similarly ethyl diphenylacetate was rather rapidly hydrogenated at 200° (a temperature about 50° lower than for ethyl phenylacetate) with the formation of a fair yield (58%) of  $\beta,\beta$ -diphenylethyl alcohol, accompanied by 1,1-diphenylethane (38%). In the case of ethyl diphenylacetate it seems probable that the enol of the ester,  $(\text{C}_6\text{H}_5)_2\text{C}=\text{COHOEt}$ , is the

compound undergoing hydrogenation. It has been shown by Staudinger and Meyer and by Cope and McElvain that this ester has so great a tendency to enolize that stable potassium and sodium derivatives of the enol may be obtained.<sup>8</sup>

The fact that the yields of alcohols previously obtained<sup>2</sup> by catalytic hydrogenation were 0% from ethyl benzoate, 97–100% from ethyl hexahydrobenzoate, 60% from ethyl phenylacetate and 93% from ethyl  $\beta$ -phenylpropionate, would lead to two tentative conclusions: (a) that a phenyl group in the 1 position with respect to a carbethoxy is completely effective, under the conditions for the hydrogenation of an ester, in stabilizing the hydrogenolysis of a carbon to oxygen linkage, and progressively less so in the 2 and 3 positions; (b) that the hydrogenation of the benzenoid ring eliminates completely the effect noted in (a). The facts reported in this paper are in general those which might be expected on the basis of these tentative conclusions. However, certain of the results of the present work would not have been anticipated. For example, despite the fact that the carbethoxy groups in diethyl phthalate are adjacent to a benzenoid ring, phthalyl alcohol and *o*-methylbenzyl alcohol were obtained by hydrogenation. This result, in spite of the fact that the carbethoxy groups in diethyl phthalate are in the 3 position with respect to each other, as in diethyl succinate, a relationship which predisposes toward hydrogenolysis of the oxygen to carbon linkage.<sup>2</sup> Further, the temperature required for hydrogenation and the yield of glycols from ethyl benzilate and diphenylacetate are not at all those that would have been anticipated upon the basis of the behavior of the simpler phenylated esters, and indicate that a tautomer of the ester is the compound undergoing hydrogenation.

### Experimental Part

The standard copper–chromium oxide catalyst used for the hydrogenations reported herewith was prepared as described for 37 KAF (p. 1140 of Ref. 2). Catalysts prepared by the same method but containing calcium, strontium, magnesium or manganese instead of barium were also used for ethylphenylacetate. In addition catalysts *ex*-carbonate (p. 1144, Ref. 2) containing barium or calcium were used as well as a catalyst *ex*-chromate containing only copper, chromium and oxygen. The ratio of catalyst to hydrogen acceptor was usually approximately 1 g. of catalyst to 8 g. of compound. The pressure of hydrogen was usually 100–170 atm. and the reactions were carried out without a solvent in the apparatus recently described.<sup>9</sup> The nickel catalyst was usually that prepared by the ammonium carbonate method<sup>10</sup> and was used in the ratio of 1 g. of catalyst to 12 g. of the hydrogen acceptor. The time for the hydrogenations was usually from one to four hours.

The following exceptions to the statements made above should be noted. Three applications of catalyst were necessary in the preparation of ethyl cyclohexylacetate. Ethanol was used as a solvent in the preparation of *o*-benzylbenzoic acid, 4-phenyl-

(8) Staudinger and Meyer, *Helv. Chim. Acta*, **5**, 656 (1922); Cope and McElvain, *THIS JOURNAL*, **54**, 4321 (1932).

(9) Adkins, *Ind. Eng. Chem., Anal. Ed.*, **4**, 342 (1932).

(10) Covert, Connor and Adkins, *THIS JOURNAL*, **54**, 1651 (1932).

butanol-1, 1,2-diphenylethane, 1,2-diphenylethanediol-1,2, and of 1,2-diphenylethanol-1. Dimethylcyclohexylamine was used as a solvent in the hydrogenation of phthalic anhydride over nickel, the reaction requiring about fourteen hours.

The ratio of products obtained in the hydrogenation of diethyl phthalate, diethyl hexahydrophthalate, ethyl benzilate varied with the length of time of reaction. The longer the time of reaction the higher the yield of hydrocarbons as contrasted with alcohols or glycols, or the yield of alcohols as contrasted with glycols.

The alcohols and glycols reported in this paper were in general characterized by their b. p. or m. p. and by the saponification value of their acetates. 4-Phenylbutanol-1 was also converted to  $\gamma$ -phenylbutyric acid, m. p. 48°. *o*-Toluic acid was characterized by its neutral equivalent. Data upon the observed physical characteristics of various products is given below: ethyl cyclohexylacetate,<sup>11</sup> 210–212° (740 mm.); 2 cyclohexylethanol-1,<sup>12</sup> 101–102° (12 mm.); *o*-hexahydrotoluic acid,<sup>13</sup> 98–99° (4 mm.); *o*-toluic acid,<sup>14</sup> m. p. 101–102°; *o*-benzyltoluene,<sup>15</sup> 278–285° (740 mm.); 4-phenylbutanol-1,<sup>16</sup> 124–127° (9 mm.); *o*-benzylbenzoic acid,<sup>17</sup> m. p. 106.5–108°; *o*-dimethylcyclohexane,<sup>17a</sup> 55–59° (8 mm.); *o*-methylhexahydrobenzyl alcohol,<sup>18</sup> 71–75° (3 mm.); 2,2-diphenylethanol-1,<sup>19</sup> 150–152° (2 mm.), m. p. 60–61°; phthalide,<sup>20</sup> m. p. 71–73°; *o*-methylbenzyl alcohol,<sup>21</sup> m. p. 32–33°; phthalyl alcohol,<sup>22</sup> m. p. 65–66.5°; hexahydrophthalyl alcohol,<sup>23</sup> 132–133° (3 mm.), m. p. 55–56°; 1,1-diphenylethanediol-1,2,<sup>24</sup> m. p. 118–120°; and 1,1-diphenylethane, 128–129° (8 mm.). Ethyl *o*-hexahydrobenzylhexahydrobenzoate (V), b. p. 155–158° (12 mm.), showed a molecular weight by saponification of 252.5, the calcd. is 252. The corresponding acid has been prepared.<sup>25</sup> The ester was further characterized by its conversion to *o*-hexahydrobenzylcyclohexylcarbinol (VI), b. p. 148–152° (10 mm.), and *o*-hexahydrobenzylmethylcyclohexane (VII), 125–131° (10 mm.), which were analyzed.

*Anal.* Calcd. for C<sub>14</sub>H<sub>26</sub>O: C, 80.00; H, 12.38. Found: C, 80.11; H, 12.27.

*Anal.* Calcd. for C<sub>14</sub>H<sub>26</sub>: C, 86.60; H, 13.40. Found: C, 86.41; H, 13.25.

### Summary

A number of esters containing phenyl or cyclohexyl groups have been submitted to hydrogenation over nickel and copper–chromium oxide catalysts with the production of various esters, glycols, alcohols, and hydrocarbons. The general nature of the results has been indicated in the paragraph preceding the experimental part.

A method has been described for the purification of ethyl  $\alpha$ -phenylacetate from halogen and nitrogen containing impurities which cannot be removed by the ordinary methods of purification.

- (11) Freundler and Damond, *Compt. rend.*, **141**, 593 (1905).
- (12) Zelinsky, *Ber.*, **41**, 2628 (1908).
- (13) Skita, *Ann.*, **431**, 20 (1923).
- (14) Hessert, *Ber.*, **11**, 238 (1878).
- (15) Zincke, *Ann.*, **161**, 94 (1872).
- (16) Braun, *Ber.*, **44**, 2871 (1911).
- (17) Ullmann, *Ann.*, **291**, 24 (1896).
- (17a) Eisenlohr, *Fortschr. Chem., Physik, physik. Chem.*, **18**, 548 (1925).
- (18) Skita, *Ann.*, **431**, 20 (1923).
- (19) Ramart and Amagat, *Ann. chim.*, [10] **8**, 290 (1927).
- (20) Wislicenus, *Ber.*, **17**, 2181 (1884).
- (21) Krober, *ibid.*, **23**, 1028 (1890).
- (22) Hessert, *ibid.*, **12**, 646 (1879).
- (23) Wieland, Schlichting and Langsdorff, *Z. physiol. Chem.*, **161**, 74 (1926).
- (24) Paal and Wiedenkauff, *Ber.*, **39**, 2063 (1906).
- (25) Willstätter and Waldschmidt-Leitz, *ibid.*, **54**, 1423 (1921).

An extensive study of copper-chromium oxide catalysts has failed to reveal any modification of the catalyst which would bring about the production of more alcohol and less hydrocarbon in the hydrogenation of ethyl phenylacetate, than does the standard type of catalyst.

MADISON, WISCONSIN

RECEIVED OCTOBER 31, 1932

PUBLISHED APRIL 6, 1933

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[CONTRIBUTION FROM THE SCHOOL OF CHEMISTRY OF THE UNIVERSITY OF MINNESOTA]

## The Jacobsen Reaction. III. The Monobromo Derivatives of the Three Tetramethylbenzenes<sup>1</sup>

BY LEE IRVIN SMITH AND CLARENCE L. MOYLE

In the previous papers of this series<sup>2</sup> it has been shown that when the polymethylbenzenes containing four or five methyl groups are allowed to stand in contact with concd. sulfuric acid, they first sulfonate, and then the sulfonic acids rearrange. These rearrangements are of at least two types: the first, shown by pentamethylbenzene, involves the migration of a methyl group from one molecule to another, while the second, shown by the tetramethylbenzenes, is merely a rearrangement of the methyl groups within the molecule. It was therefore of interest to investigate the monobromo derivatives of the tetramethylbenzenes, because these are pentasubstituted benzenes in which the substituents differ in nature as well as in position, and, consequently, if they were to rearrange in a manner similar to pentamethylbenzene, either a bromine atom or a methyl group could migrate and so lead to different products. There are several references in the literature to migrations of halogens among the benzene derivatives, but only two concern the bromotetramethylbenzenes. Jacobsen<sup>3</sup> reported that a mixture of bromodurene and concd. sulfuric acid gradually became dark and evolved considerable sulfur dioxide, and from this mixture he isolated and identified five products: *viz.*, dibromodurene, prehnitene sulfonic acid, two isomeric pseudocumene sulfonic acids, and small amounts of hexamethylbenzene. In addition to these five products, Jacobsen reported a small amount of brown amorphous material, and stated that no brominated sulfonic acids were formed. Tohl<sup>4</sup> investigated the action of sulfuric acid on bromoprehnitene, and reported dibromoprehnitene and prehnitene sulfonic acid as the products.

In the present work, it has been found that bromodurene, in the presence of sulfuric acid under various conditions of time, temperature and strength

(1) Abstracted from a thesis by Clarence L. Moyle, presented to the Graduate Faculty of the University of Minnesota, in partial fulfillment of the requirements for the degree of Master of Science, June, 1932. Presented at the 84th meeting of the American Chemical Society, Denver, Colo., August, 1932. Paper VIII on the Polymethylbenzenes; VII, *THIS JOURNAL*, **54**, 1614 (1932).

(2) Smith and Lux, *ibid.*, **51**, 2994 (1929); Smith and Cass, *ibid.*, **54**, 1614 (1932).

(3) Jacobsen, *Ber.*, **20**, 2837 (1887).

(4) Tohl, *ibid.*, **25**, 1527 (1892).