tors[22,23] has called attention to the fact that the Friedel–Crafts reactions of a number of primary derivatives exhibit characteristics of a bimolecular displacement mechanism, rather than a carbonium ion mechanism. However, one should not lose sight of the fact that there are still some features of reactions of primary derivatives (as well as those of secondary, which have been adequately recognized) which are not compatible with a simple displacement process. The present work shows that the *major* result of alkylation with *n*-propyl and *n*-butyl chlorides even at low temperature is rearranged product. The fact that the exclusive product from isobutyl chloride is the *t*-butyl derivative, which has now been confirmed, has received little comment in discussions of alkylation mechanisms. The rearrangements accompanying Friedel–Crafts alkylations with these primary halides may involve σ- or π-complexes in a mechanism analogous to that proposed by Streitwieser, Schaeffer and Andreades[4b] for alkylations with alcohols and boron trifluoride. However, it is also possible that the alkyl halides are isomerized prior to alkylation. Further experimental data will be required before a choice can be made between these alternatives.

(22) (a) H. C. Brown and M. Grayson, THIS JOURNAL, **75**, 6285 (1953); (b) H. C. Brown and H. Jungk, *ibid.*, **78**, 2182 (1956); (c) H. Jungk, C. R. Smoot and H. C. Brown, *ibid.*, **78**, 2185 (1956).

(23) K. L. Nelson and H. C. Brown, Chapter 56 in B. T. Brooks, S. S. Kurtz, Jr., C. E. Boord and L. Schmerling, "The Chemistry of Petroleum Hydrocarbons," Reinhold Publishing Corp., New York, N. Y., 1955, Vol. 3, p. 465.

Acknowledgment.—We are grateful to the National Science Foundation for a grant which supported this research.

AUSTIN 12, TEX.

[CONTRIBUTION NO. 357 FROM THE DEPARTMENT OF ORGANIC CHEMISTRY AND ENZYMOLOGY, FORDHAM UNIVERSITY]

Investigations on Lignins and Lignification. XXII.[1] The Conversion of D-Glucose into Lignin in Norway Spruce

BY SAMUEL N. ACERBO, WALTER J. SCHUBERT AND F. F. NORD

RECEIVED JUNE 22, 1959

The formation of lignin in plants follows the scheme: carbohydrate → shikimic acid → *p*-hydroxyphenylpyruvic acid → lignin building stones → lignin. The carbohydrate has been identified as glucose.

From the viewpoint of plant physiology, the chemistry of wood is but a special case of the utilization by plants of the carbon absorbed from the atmosphere as carbon dioxide. But for the wood chemist, this raw material represents a difficult and intriguing substance: difficult because the components of which wood is comprised are very complex; intriguing because about one-half of the substance of wood has proven extremely difficult to exploit chemically on a scale even nearly comparable with that of the manufacture of paper.

When softwoods are subjected to the pulping process for paper manufacture, approximately one-half of the wood is dissolved. Of the dissolved material, about one-half again consists of the aromatic polymer, lignin. It is the lignin which gives wood its rigidity, and it is precisely the lignin of wood which has resisted exploitation, but may, at some future time, provide the basic raw material for new chemical industries.

The mechanism of the biogenesis of lignin in living plants remained obscure until the role of shikimic acid in the lignification process was brought to light in 1955.[2] Shikimic acid (I) was originally found to function as an intermediate in the biogenesis, from glucose, of the aromatic ester, methyl *p*-methoxycinnamate, by the mold *Lentinus lepideus*, which is a species of wood-rotting fungi which has the capacity, when growing in its natural habitat, of removing the cellulose from sound wood, *i.e.*, of producing "brown rot." In addition, this fungus also possesses among its metabolic activities the ability to convert carbohydrates into methyl *p*-methoxycinnamate.[3a,b] As the result of certain metabolic studies carried out in this Laboratory,[4] the biogenesis of methyl *p*-methoxycinnamate by *L. lepideus* may be formulated as: cellulose → glucose → sedoheptulose → shikimic acid → *p*-hydroxyphenylpyruvic acid → methyl *p*-methoxycinnamate.

The structural similarity of methyl *p*-methoxycinnamate (II) to the postulated building stones of lignin,[5] namely *p*-coumaryl alcohol (III), coniferyl alcohol (IV) and sinapyl alcohol (V), indicated a possible relationship between the biosynthesis of the ester II and the biogenesis of lignin. The intervention of shikimic acid in lignification was clearly demonstrated[6] by the feeding of specifically labeled shikimic acid (containing C^{14} in positions 2 and 6 of its cyclohexene ring) to growing sugar cane plants, and the subsequent recovery of a radioactive lignin yielding on oxidation vanillin (VI) which retained the isotopic activity of the C^{14} in the corresponding positions

(1) For papers XIX and XX see S. N. Acerbo, W. J. Schubert, H. Shimazono and F. F. Nord, THIS JOURNAL, **80**, 1990, 1992 (1958); for paper XXI see H. Shimazono, *Arch. Biochem. and Biophys.*, **83**, 206 (1959). This investigation was supported in part by grants of the National Science Foundation, the U. S. Atomic Energy Commission and the U. S. Public Health Service. Parts of this paper are taken from a portion of a dissertation to be submitted by S. N. A. to the Graduate Faculty of Fordham University, 1960. In addition, S. N. A. wishes to thank Drs. H. Shimazono and H. Stockmann of this Department for many enlightening discussions.

(2) G. Eberhardt and F. F. Nord, *Arch. Biochem. and Biophys.*, **55**, 578 (1955).

(3) (a) F. F. Nord and J. C. Vitucci, *Arch. Biochem.*, **14**, 243 (1947); (b) **15**, 465 (1947).

(4) G. Eberhardt, THIS JOURNAL, **78**, 2832 (1956).

(5) P. Klason, *Svensk Kemisk Tidskr.*, **9**, 133 (1897).

(6) G. Eberhardt and W. J. Schubert, THIS JOURNAL, **78**, 2835 (1956).

of its benzene ring. The retention of the integrity of the cyclohexene ring of shikimic acid during the course of its conversion into the benzene rings of lignin represents direct evidence for the mediation of shikimic acid as an intermediate in the lignification process.

The implication of *p*-hydroxyphenylpyruvic acid (VII) in the biogenesis of methyl *p*-methoxycinnamate (II) by *L. lepideus*[4] prompted an investigation of its possible function in lignification as well. Using the approach successfully employed to demonstrate the intervention of shikimic acid in this process,[6] *p*-hydroxyphenylpyruvic acid has been found to serve[7a,b] as a common precursor of the lignin building stones (III, IV, V).[7c]

These findings then reveal the following over-all scheme[8a,b] for the lignification process: carbohydrate → shikimic acid → *p*-hydroxyphenylpyruvic acid → lignin building stones → lignin.

The importance of the shikimic acid → *p*-hydroxyphenylpyruvic acid interconversion in lignification then poses the problem of the identity of the carbohydrate from which these lignin precursors are ultimately derived. Many conjectures have been advanced relative to the nature of the carbohydrate precursor, but these suggestions have been referred to as purely speculative.[9]

In a preliminary experiment,[10] uniformly labeled D-glucose was fed to a Norway spruce tree, and, after a suitable period of metabolism, radioactivity was detected in the cambium layer of the tree. The lignin of this layer was isolated and found to be radioactive. Hence, the tree was able to convert fed glucose into lignin. In the present report, the fate in the lignification process of glucose samples which are specifically labeled with C^{14} in their number 1 and 6 positions (VIII) is also studied.

(7) (a) F. F. Nord, W. J. Schubert and S. N. Acerbo, *Naturwiss.*, **44**, 35 (1957); (b) THIS JOURNAL, **79**, 251 (1957); **80**, 1990 (1958).

(7c) Compare also: K. Kratzl and G. Billek, *Monatsh. f. Chem.*, **90**, 536 (1959).

(8) (a) W. J. Schubert and F. F. Nord, *Advances in Enzymol.*, **18**, 349 (1957). (b) See: *Note added in proof.*

(b) NOTE ADDED IN PROOF.—No contributions from K. Freudenberg have been forthcoming relevant to this aspect of the mechanism of lignification. However, in two disputanda emanating from his laboratory subsequent to a review on Lignin and the Formation of Wood" by Nord and Schubert (*Experientia*, **15**, 245 (1959)), the writer has avoided the main and fundamental issue. In the first attack (*Experientia*, **16**, in press (1960)) (guided by Freudenberg), he writes: "All in all, Nord and Schubert have merely described a pair of random steps isolated from the complexity of the total process of lignification and hence convey an oversimplified, distorted picture of the overall scheme." While in the second (agreed to by Freudenberg) he states (*Experientia*, **16**, in press (1960)): "The experimental work done by Nord and his collaborators is not at variance with our conception of the biogenesis and constitution of lignin. . . ."

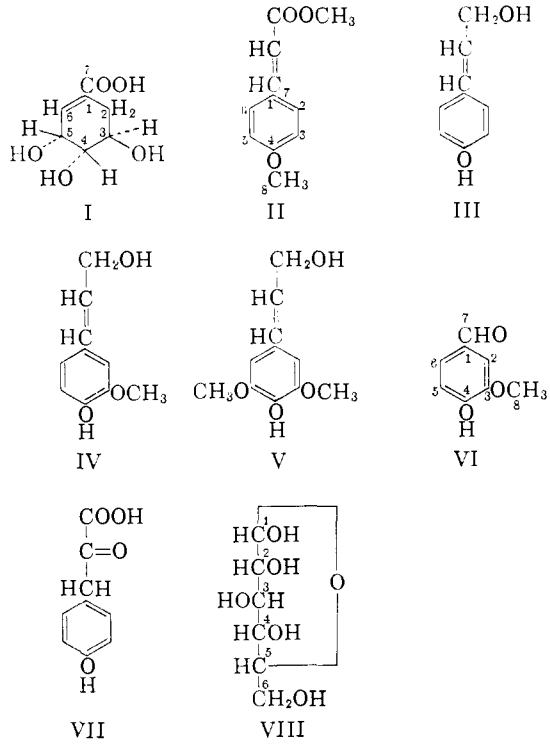
Albeit, the contrary appears to be true. Freudenberg derives his attitude toward native lignin from the properties of an inhomogeneous mixture obtained by acetone extraction (*Chem. Ber.*, **90**, 2857 (1957)), while this laboratory has isolated and studied electrophoretically homogeneous (THIS JOURNAL, **75**, 1869 (1953)) lignin preparations which were either enzymically liberated or extracted with *alcohol* according to Brauns. Conclusions based on the properties of a mixture are obviously deceptive, not only for the reader but also for the authors themselves. Meanwhile the ill-conceived attempt to construct an issue regarding the bringing to light of the role of shikimic acid in lignification is strongly reminiscent of the *de facto* priority involved in the procedure for the alkaline nitrobenzene oxidation of lignin to vanillin.

(9) F. F. Nord and J. C. Vitucci, *Advances in Enzymol.*, **8**, 253 (1948).

(10) W. J. Schubert and S. N. Acerbo, *Arch. Biochem. and Biophys.*, **83**, 178 (1959).

Experiments and Results

Experiment with Uniformly Labeled D-Glucose.—One mc. of uniformly labeled D-glucose-C^{14} (Tracerlab) totaling 1.030 g. was fed to a Norway spruce tree. This was accomplished in four separate feedings at 7-day intervals as follows: 257 mg. of the uniformly labeled glucose was dissolved in 50 ml. of water, and an equimolar amount of KH_2PO_4 was added. The solution was divided into 5 aliquots of 10 ml. each which were placed in individual test-tubes. Five upper branches of the tree were used for the incorporation. The tips of the needles at the ends of these branches were clipped, and the branch endings were immersed into the solution of the tagged glucose. After 7 days, the solution was completely absorbed into the tree, and another 257-mg. aliquot of glucose was fed in a similar manner. A total of four feedings was conducted and, on their completion, the tree was cut down. The needles and



bark were discarded, and the branches were removed. Except for the branches used for the incorporation, the cambium layer of the residual trunk contained most of the radioactivity. This layer was air-dried, milled to 60 mesh and re-dried. The sawdust was then subjected to an oxidation,[11] and the resulting $BaCO_3$ was collected and its activity counted (Table I). The lignin of the sawdust was isolated by a standard method[12] and found to represent 28% of the weight of the sawdust.[13] An infinitely thick layer of $BaCO_3$ was collected from an oxidation of the lignin, and its radioactivity was recorded (Table I).

TABLE I

DISTRIBUTION OF ACTIVITY IN THE PLANT MATERIAL

Plant material	Uniform C^{14}-glucose (1.0 mc.)	Activity, c./min./mg. C: glucose-1-C^{14} (1.0 mc.)	glucose-6-C^{14} (0.25 mc.)
Stem	460	1780	620
Lignin	240	770	200
Vanillin	..	40	50

Experiments with Specifically Labeled D-Glucose.—One mc. of D-glucose-1-C^{14} (Tracerlab.) (38 mg.) and 0.25 mc.

(11) D. D. Van Slyke and J. Folch, *J. Biol. Chem.*, **136**, 509 (1940).

(12) W. J. Wald, P. F. Ritchie and C. B. Purves, THIS JOURNAL, **69**, 1371 (1947).

(13) G. J. Ritter, R. M. Seborg and R. L. Mitchell, *Ind. Eng. Chem., Anal. Ed.*, **4**, 202 (1932).

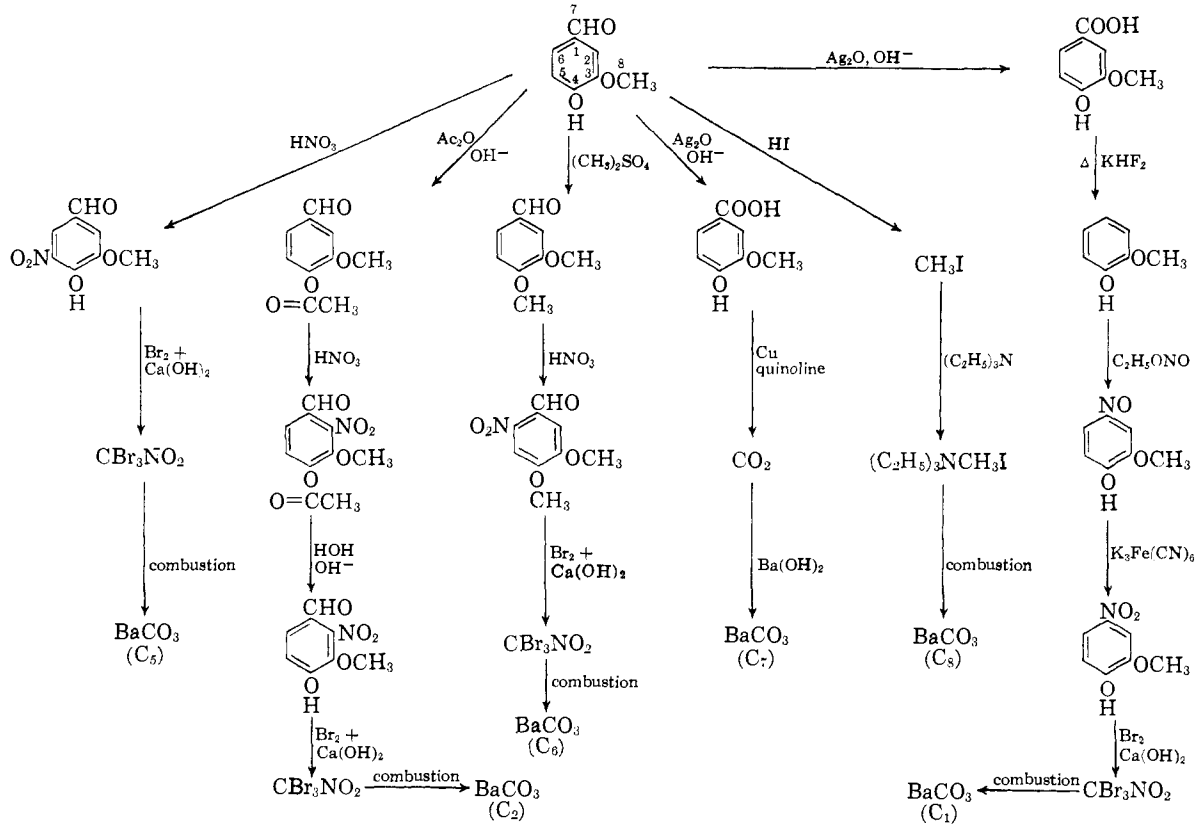


Fig. 1.

of D-glucose-6-C^{14} (515 mg.)[13a] were fed separately to individual Norway spruce trees. The feeding and isolation of lignin were conducted as described above. The lignin was subjected to alkaline nitrobenzene oxidation,[14] and one of its degradation products, vanillin, was isolated. Carbons 1, 2, 5, 6, 7 and 8 of the vanillin were isolated by means of the reactions shown in the degradation scheme (Fig. 1).

For C_1: vanillin (1.3 mM) → vanillic acid,[15] m.p. 210° (66%), → guaiacol[16] (77%) → 5-nitrosoguaiacol[17] (90%) → 5-nitroguaiacol, m.p. 103° (62%), → bromopicrin[18] (74%) → $BaCO_3$, 63 mg.; total yield from vanillin to C_1:26%.

For C_2: vanillin (1 mM) → vanillin acetate (85%) → 2-nitro-acetylvanillin → 2-nitrovanillin,[19] m.p. 134° (47%), → bromopicrin (77%) → $BaCO_3$,[11] 66.4 mg., total yield from vanillin to C_2: 28%.

For C_5: vanillin (1 mM) → 5-nitrovanillin[20] (68%), m.p. 174°, → bromopicrin (68%) → $BaCO_3$, 77.6 mg., total yield from vanillin to C_5: 39%.

For C_6: vanillin (1 mM) → veratraldehyde[21] (95%) → 6-nitroveratraldehyde,[22] m.p. 132° (72%), → bromopicrin (41%) → $BaCO_3$, 46 mg., total yield from vanillin to C_6: 22%.

For C_7: vanillin (0.5 mM) → vanillic acid, m.p. 210°, → $BaCO_3$,[18] 45 mg., total yield from vanillin to C_7: 50%.

For C_8: vanillin (0.08 mM) → triethylmethylammonium iodide[23] (63%) → $BaCO_3$, 67 mg., total yield from vanillin to C_8: 62%.

From the data of Table I it is obvious that the activity of the uniformly labeled D-glucose fed to the tree was appreciably incorporated into its lignin. Thus, it is apparent that the tree was able to convert this fed glucose into lignin.

The activities of the materials and compounds obtained by the degradation of the lignin from the specifically labeled D-glucose experiments are shown in Table II.

TABLE II

DISTRIBUTION OF ACTIVITY IN VANILLIN FORMED FROM D-GLUCOSE-1-C^{14} AND D-GLUCOSE-6-C^{14}

Positions in vanillin	D-glucose-1-C^{14} (1 mc.) C./min./mM	% of vanillin	glucose-6-C^{14} (0.25 mc.) C./min./mM	% of vanillin
Vanillin	3850	100.0	4850	100.0
Carbon-1	100[b]	2.6	220[b]	4.5
Carbon-2	700	18.2	780	16.1
Carbon-5	120[b]	3.1	190[b]	3.9
Carbon-6	440[b]	11.4	880	18.1
Carbon-7	1100	28.5	1070	22.0
Carbon-8	1200[b]	31.1	1200[b]	24.7
Carbon-3,4[a]	..	5.1	..	10.7

[a] Calculated values. [b] Observed activity (corrected for background) was less than background count. Sufficient counts were taken to give a probable error of 5%.

It can be seen from Table II that relative to the total amount of C^{14} originally fed to the plant, more of the activity of carbon 6 than that of carbon 1 of glucose was incorporated into the aromatic rings of the lignin. Thus, each product obtained by the degradation of the lignin from D-glucose-6-C^{14} is more active than the corresponding compound from D-glucose-1-C^{14}.

(13a) R. Schaffer and H. S. Isbell, *J. Research Natl. Bur. Standards*, **56**, 191 (1956), RP2667.
(14) Schimmel and Co., German Patent 693,350 (1940).
(15) A. C. Cope in *Org. Syntheses*, **30**, 101 (1950).
(16) L. Reio and G. Ehrensvärd, *Arkiv Kemi*, **5**, 301 (1953).
(17) H. Rupe, *Ber.*, **30**, 2446 (1897).
(18) J. Baddiley, G. Ehrensvärd, E. Klein, L. Reio and E. Saluste, *J. Biol. Chem.*, **183**, 777 (1950).
(19) I. Pisovschi, *Ber.*, **43**, 2137 (1910).
(20) I. Pearl and D. Beyer, *J. Org. Chem.*, **16**, 219 (1951).
(21) K. Rosenmund, *Ber.*, **43**, 3415 (1910).
(22) E. B. Marr and M. T. Bogert, THIS JOURNAL, **57**, 1329 (1935).
(23) S. A. Brown and R. U. Byerrum, *ibid.*, **74**, 1523 (1952).

The comparative distribution of activity in the vanillin from the two experiments shows that appreciable activity was incorporated into carbons 2, 6, 7 and 8 of the vanillin, whereas only insignificant amounts were incorporated into the other positions. These results are similar to those obtained for the shikimic acid[24] and methyl *p*-methoxycinnamate[25] biosyntheses from glucose.

In the case of the biosynthesis of methyl *p*-methoxycinnamate by *Lentinus lepideus* from D-glucose-1-C^{14} and D-glucose-6-C^{14}, the isotopic activity of the ester was greater than that of glucose. However, the incorporation of the tagged glucose into lignin involved considerable dilution of the activity with non-radioactive glucose already existing in the plant. Hence, the degree of incorporation of tagged glucose into lignin should not be compared with its incorporation into the ester by the mold where dilution with non-radioactive glucose could not occur.

Previously[8a,9] we have asserted that both the fungal and the plant biosyntheses to phenylpropane units followed a similar pathway. The similarity of carbon-14 distribution from D-glucose-1-C^{14} and D-glucose-6-C^{14} in the aromatic rings of the ester and of the vanillin derived from lignin oxidation shows that a marked similarity in metabolic pathways does indeed exist in both living systems (Table III).

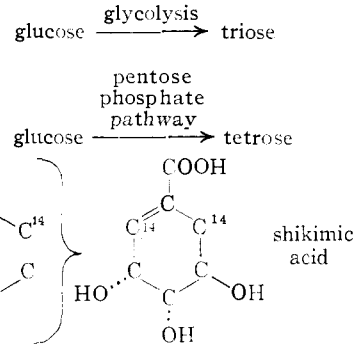
TABLE III

DISTRIBUTION OF ACTIVITY IN METHYL *p*-METHOXYCINNAMATE FORMED FROM D-GLUCOSE-1-C^{14} AND D-GLUCOSE-6-C^{14}[25]

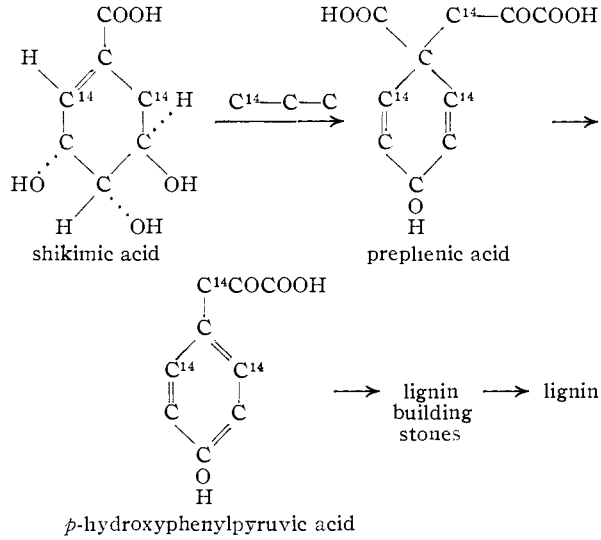
Positions in methyl *p*-methoxycinnamate:carbon	Glucose-1-C^{14} (% of ester)	Glucose-6-C^{14} (% of ester)
1	..	3.2
3 + 5	..	4.9
4	..	4.2
2 + 6	..	39.1
7	14.1	17.6
8	13.2	12.6

From the comparative data, it is apparent that both the ester and the vanillin incorporate most of the activity in carbons 2, 6, 7 and 8. Methyl labeled sodium pyruvate was also force-fed to a Norway spruce tree, the lignin of which proved to be radioactive. However, the vanillin obtained upon degradation of the lignin was nonradioactive.

When these facts, together with the observation of the non-incorporation of acetate[4] into the aromatic ring of the ester, are related to the mode of incorporation of glucose into the previous compounds, the tricarboxylic acid cycle is eliminated as a participant in the biosynthesis of aromatic nuclei. The mode of formation of shikimic acid from glucose,[24] together with the mode of formation of the aromatic rings of vanillin,[6] indicates that glucose is converted into shikimic acid by the condensation of a triose (such as phosphoenol pyruvic acid) derived from glucose *via* the Embden-Parnas-Meyerhof glycolysis, with a tetrose (such as D-erythrose 4-phosphate) derived from glucose *via* the pentose phosphate pathway. This affords an explanation for the activity in positions 2 and 6 of the rings of shikimic acid and of vanillin, *i.e.*



In the formation of *p*-hydroxyphenylpyruvic acid, shikimic acid condenses with a 3-carbon fragment derived from products of glycolysis above the level of pyruvate, or from glucose itself, concomitant with the decarboxylation of carbon 7 of prephenic acid.[26] This would explain the activity in position 7 of vanillin, *i.e.*



p-hydroxyphenylpyruvic acid

p-Hydroxyphenylpyruvic acid then serves as an intermediate between shikimic acid and the lignin building stones which eventually polymerize into lignin itself.[7a,b]

Regarding carbon-8, it has been demonstrated,[27] that the methyl group of methionine serves as a precursor to the methyl group of vanillin isolated from lignin, and that formate, or some one-carbon compound, is reduced to a labile methyl group of methionine. Since carbon-8 of vanillin was found to be radioactive (Table II), it is possible that a 1-carbon fragment derived from glucose is converted to the labile methyl group in methionine, which is then used for methylation reactions.

Discussion

The process of lignification may now be expressed as follows: The ultimate organic source of lignin is the carbohydrate photosynthetically

(24) P. R. Srinivasan, H. T. Shigeura, M. Sprecher, D. B. Sprinson and B. D. Davis, *J. Biol. Chem.*, **220**, 477 (1956).

(25) H. Shimazono, W. J. Schubert and F. F. Nord, THIS JOURNAL, **80**, 1992 (1958).

(26) B. D. Davis, *Advances in Enzymol.*, **16**, 247 (1955).

(27) R. U. Byerrum, J. H. Flokstra, L. J. Dewey and C. D. Ball, *J. Biol. Chem.*, **210**, 633 (1954).

formed by the plant from atmospheric carbon dioxide. This carbohydrate has now been identified as D-glucose. The monosaccharide is then cyclized to shikimic acid. This cyclohexene derivative is then aromatized, probably *via* the prephenic acid pathway, to *p*-hydroxyphenylpyruvic acid. This phenylpropane derivative then serves as a common precursor for the primary lignin building stones (III, IV, V) by a series of successive oxidation and methylation reactions.[28] For example, in softwoods, two building stones (III and IV) may form lignin by repeated condensations. However, for the formation of hardwood lignins, a syringyl-type building stone (V) is also required before the final polymerization into the higher methoxyl-containing lignins characteristic of hardwood species.

(28) F. F. Nord and G. De Stevens, in "Handbuch d. Pflanzenphysiol.," Vol. X, J. Springer, Heidelberg, 1958, p. 389.

NEW YORK 58, N. Y.

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

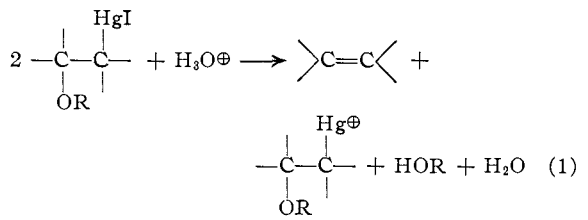
The Nature of the Rate-determining Step in Deoxymercuration[1]

BY MAURICE M. KREEVOY AND FRANCES R. KOWITT

RECEIVED JUNE 5, 1959

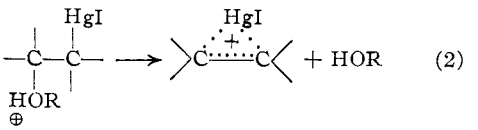
For deoxymercuration of α-2-methoxycyclohexylmercuric iodide by non-halogen acid $\Delta H^{\ddagger}$ is 17.75 ± 0.19 kcal. mole^{-1} and $\Delta S^{\ddagger}$ is 4.6 ± 0.6 cal. mole^{-1} deg.$^{-1}$. For the same reaction of the β-isomer $\Delta H^{\ddagger}$ is 26.2 ± 0.7 kcal. mole^{-1} and $\Delta S^{\ddagger}$ is 4.5 ± 2.0 cal. mole^{-1} deg.$^{-1}$. In both cases, strong evidence is presented that a fast, prototropic equilibrium precedes the rate-determining step. From this it is concluded that the rate-determining step in deoxymercuration is the conversion of the protonated substrate to the mercuric olefin complex, and that the α-isomer has the *trans* configuration. Other pertinent findings are discussed in terms of this mechanism.

In previous work[2] it has been shown that the first step in reaction 1 is



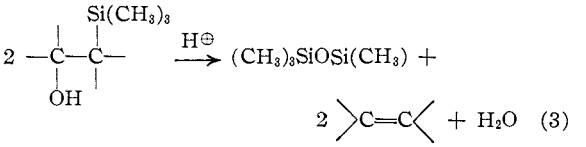
(1)

the reversible protonation of the substrate oxygen, and that the rate-determining step is some sort of reaction of the protonated substrate not involving the formation of covalent bonds to the solvent. The present paper confirms these conclusions and reports that the enthalpy of activation for reaction 1 with α-2-methoxycyclohexylmercuric iodide (I) is 8.4 kcal. mole^{-1} lower than that for the β-isomer (I). Since the entropies of activation are essentially the same, the reaction of I is 10^5–10^7 times faster than that of II, depending on the temperature of comparison. From these facts it is concluded that the rate-determining step in reaction 1 is the formation of the olefin–mercuric iodide complex, as shown in equation 2, and that compound I must be the *trans* isomer. Other facts about oxymercuration and deoxymercuration[3,4] are shown to be consistent with this interpretation.



(2)

It is suggested that reaction 3, and perhaps other reactions of organometallic compounds, utilize the same sort of rate-determining step.



(3)

The nature of the transition state for reaction 2 and of the olefin–mercuric iodide complex are discussed.

Results

Products.—In both cases the ultraviolet spectrum of the product was essentially identical with that expected if each mole of substrate produced half a mole of HgI_2. When 0.5 g. of II was treated with excess 12 *M* $HClO_4$ and the solution then neutralized, methanol was obtained, identified by its infrared spectrum. Exactly the same result was obtained with I. Since I exhibits a reaction rate not too different from that of 2-methoxy-1-iodomercuripropane (III), it presumably produces analogous products. On the basis of these facts, the stoichiometry shown in equation 2 was assumed for both I and II.

The Rate Law.—Good first-order kinetics were observed in all reactions. No catalysis by products (reported for III[2]) could be observed with I and II. As before,[2] rates were measured spectrophotometrically at substrate concentrations around 10^{-4} *M*. Pseudo first-order rate constants, k_1, were evaluated as previously described.[2]

Dependence of Rate on Acidity, I.—At 25° and 3.64 × 10^{-4} *M* aqueous perchloric acid, k_1 had a value of 2.11 ± 0.10 × 10^{-3} sec.$^{-1}$ for I.[5] This gives k_2 ($k_2 = k_1/H^{\oplus}$) a value of 5.8 ± 0.3 l. mole^{-1} sec.$^{-1}$. The rates were too fast to permit the constancy of k_2 to be verified by measurements at higher perchloric acid concentrations.

(1) Presented, in part, before the division of Organic Chemistry, 135th Meeting of the American Chemical Society, Boston, Mass., April, 1959.

(2) M. M. Kreevoy, THIS JOURNAL, **81**, 1099 (1959).

(3) G. F. Wright, *Ann. N. Y. Acad. Sci.*, **65**, 436 (1957).

(4) J. Chatt, *Chem. Revs.*, **48**, 7 (1951).

(5) (a) In this paper, whenever a value is reported with a measure of its uncertainty in this fashion, the value is the mean of two or more determinations and the uncertainty is the average deviation from the mean. (b) The aqueous solutions referred to in this paper contained up to 2% of methanol.