25 cc. of an aqueous solution containing 0.3 g. of *m*-nitrobenzoic hydrazide. A yellow precipitate formed almost immediately. The mixture was allowed to stand on the water-bath for half an hour, and at room temperature overnight. The precipitate was filtered off on to a sintered glass filter, washed with distilled water and dried to constant weight. Yield of condensation product, 0.2321 g.; vanillin yield, 0.112 g. (factor = 0.4829). *Anal.* of original product, without recrystallization. Calcd. for vanillin *m*-nitrobenzoylhydrazone: OCH_3, 9.84. Found: OCH_3, 9.74.

When 0.1000 g. of vanillin dissolved in 50 cc. of water was boiled for twenty hours with 12 g. of sodium hydroxide, acidified and extracted as described, 92% of the original vanillin was recovered.

When 0.1000 g. of vanillin dissolved in 50 cc. of water was treated in identical manner but without boiling the alkaline solution, 96.6% of the original vanillin was recovered.

By the use of this method of extraction and estimation the vanillin is recovered almost quantitatively, and the original condensation product obtained from the alkaline-treated waste liquor is sufficiently pure to allow a direct calculation of yield. The loss of vanillin due to the Cannizzaro reaction is slight. The values obtained in Tables II, III, IV were obtained by this method.

Effect of Alteration in the Waste Sulfite Liquor on Vanillin Yield.—The alcohol–benzene extracted spruce wood meal gave the following analysis: moisture, 8%; on a water-free basis, OCH_3, 4.9; lignin, 27.0.[13] In each run a 10-g. sample of spruce wood meal (9.2 g. on water-free basis) was sealed in a stainless steel autoclave of 120-cc. capacity with 100 cc. of bisulfite cooking liquor of the desired concentration. The same preliminary temperature schedule was used in each case. The bomb was heated to 100° in the course of thirty minutes, maintained at 100–110° for sixty minutes and then heated to the specified temperature (say 125°) in the next thirty minutes. It was maintained at this temperature for the desired length of time, and then withdrawn from the bath and cooled by quenching in cold water. The pulp was filtered off, washed and its yield and lignin content determined. The liquor and wash solution were concentrated under reduced pressure at 40° to 50 cc., and this solution was boiled under reflux with 12 g. of sodium hydroxide for twelve hours in an atmosphere of nitrogen. The solution was acidified, and the vanillin which had formed was extracted and estimated by the new method described above. The lignin content of the liquor was obtained by subtracting the lignin content of the pulp from the 2.48 g. in the original wood meal. The results obtained in a number of these experiments are summarized in Table V.

Summary

1. The formation of vanillin by the action of hot alkalies on waste sulfite liquor has been confirmed and a satisfactory method developed for its estimation and quantitative extraction from the reaction mixture.

2. The effect on vanillin yield of variations in the alkaline cooking treatment has been studied.

3. Using a standard method of vanillin formation, the effect of alteration in the nature of the sulfite liquor from spruce wood has been investigated.

MONTREAL, CANADA RECEIVED NOVEMBER 18, 1935

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(13) Method of Ritter, Seborg, and Mitchell *Ind. Eng. Chem., Anal. Ed.*, **4**, 202 (1932).

[CONTRIBUTION FROM THE DIVISION OF INDUSTRIAL AND CELLULOSE CHEMISTRY, PULP AND PAPER RESEARCH INSTITUTE, McGILL UNIVERSITY]

Studies on Lignin and Related Compounds. XXV. Mechanism of Vanillin Formation from Spruce Lignin Sulfonic Acids in Relation to Lignin Structure[1]

BY GEORGE H. TOMLINSON, 2ND, AND HAROLD HIBBERT

In previous investigations on the formation of vanillin from waste sulfite liquors[2] no proof has been given that its formation actually results from a decomposition of the lignin sulfonic acids present. Hoffmeister[3] has stated that hadromal, which he considers identical with coniferyl aldehyde, exists to the extent of 3% in wood (oak) and the possibility thus exists that this or some other non-ligneous constituent of the liquor may be the source of the vanillin.

Discussion

All of the spruce lignin sulfonic acid fractions prepared both by the use of calcium and of potassium bisulfites, and described in a previous communication,[4] were found to yield vanillin on treatment with alkali (Table I). The vanillin from each of these fractions was formed under standard conditions (19.4% sodium hydroxide) and determined analytically as the *m*-nitrobenzoyl-

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(1) Abstracted from a thesis "The Formation of Vanillin from Lignin Sulfonic Acids and its Relation to the Structure of Lignin" presented by George Tomlinson to McGill University in partial fulfilment of the requirements for the Ph.D. degree, April, 1935.

(2) For list of references see Part XXIV, THIS JOURNAL, **58**, 345 (1936).

(3) Hoffmeister, *Ber.*, **60**, 2062 (1927).

(4) Part XXIII, THIS JOURNAL, **58**, 340 (1936).

TABLE I

FORMATION OF VANILLIN FROM PURIFIED SPRUCE LIGNIN SULFONATES[a]

Yield and analysis of lignin sulfonates, vanillin yield and analysis of fission products

Fraction	% L. S. A. isolated	% S[b]	% OCH_3[b]	% OCH_3 on "lignin" on $CaSO_3H$-free basis	% vanillin[b]	% vanillin on "lignin"	% S of fission product[b]	% OCH_3 of "lignin" in fission product
Ca L. S. A. α-I[c]	19	9.7	11.6	15.4	4.5	6.1	4.4	14.9
Ca L. S. A. α-II	44	10.0	11.8	15.8	4.9	6.6	...	..
Ca L. S. A. β	37	11.0	11.0	15.2	6.0	8.4	...	..
	total 100%							
K L. S. A. I[d]	70	5.6	13.3	15.5	5.5	6.4	0.9	15.5
K L. S. A. II	16	7.0	12.8	15.3	7.1	8.6	...	..
K L. S. A. III	14	6.0	9.8	11.5	6.1	7.1	2.4	15.5
	total 100%							
K L. S. A. II + III	30	..	11.1	..	6.8	...	2.1	15.8

[a] Described in Part XXIII of this paper.[4] [b] Calculated on calcium- or potassium-free basis. [c] Calcium lignin sulfonates prepared by cooking wood meal for twelve hours at 125°. [d] Potassium lignin sulfonates prepared by cooking wood meal for twenty-one hours at 110°.

hydrazone. The vanillin was also isolated in pure crystalline form.

As the sulfur contents of the fractions differed appreciably the vanillin yield (6.1 to 8.6%) was calculated on a metallic ion and SO_3H-free basis. The fact that the lignins from one liquor were more highly sulfonated than those from the other had no marked bearing on the vanillin yield, but it was noted that in the individual liquors the products with the higher sulfur contents gave higher yields of vanillin.

The lignin fractions precipitated on acidification of the reaction mixture obtained in the alkaline treatment of the lignin sulfonic acids will be referred to as "lignin fission products." These compounds show a lower sulfur content than the original lignin sulfonic acids, presumably due to the hydrolysis of certain of the SO_3H radicals (Table I). It was found that those more highly sulfonated resulted from the more highly sulfonated lignin sulfonic acids. It is probable that the SO_3H radicals in the latter are combined with different groupings, since only certain of these radicals are readily hydrolyzed with alkali.

The fission products from the different fractions of the liquor show almost identical methoxyl content (15.5–15.8%) when calculated on an SO_3H-free basis. The fact that this value is no lower than that of the original lignin indicates that in addition to the vanillin (OCH_3, 20.4), a small non-methylated aliphatic fragment has been split off.

Fully methylated lignin sulfonic acids were found to yield veratric aldehyde on treatment with alkali. Unlike vanillin, veratric aldehyde shows a marked tendency to undergo the Cannizzarro reaction in alkaline solution, and its actual isolation presents certain difficulties. Decker and Pschorr[5] have shown that it is quantitatively converted into the corresponding acid and alcohol in one hour in concentrated alkaline solution.[6] In this investigation it was found that on boiling with 7.4% sodium hydroxide, veratric aldehyde decomposes to the extent of 35% in one hour, but with 3.8% sodium hydroxide the decomposition is only 7.1%. It is therefore necessary to use a dilute alkaline solution and to remove the veratric aldehyde as soon as formed.

The methylated lignin sulfonic acid was boiled in a distilling flask with dilute sodium hydroxide (3.8%). The original volume of this solution was maintained by the continual addition of water, and the veratric aldehyde which distilled with the water vapor was determined analytically in the distillate as veratric *m*-nitrobenzoylhydrazone.

After thirty-six hours of treatment the yields from methylated fractions K L. S. A. I and K L. S. A. (II + III) were 2.35 and 2.76%, respectively, when calculated on a potassium- and SO_3H-free basis. These values are quite comparable with that of vanillin (3.5%) as obtained from fraction K L. S. A. I using the same alkali concentration. They are, however, considerably lower than the vanillin yields obtained under optimum conditions, due apparently to an incomplete fission reaction in dilute alkaline solution.

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(5) Decker and Pschorr, *Ber.*, **37**, 3403 (1904).

(6) The Cannizzarro reaction is characteristic of most aromatic aldehydes, but it is curious that vanillin and veratric aldehyde should show such marked difference with respect to this reaction. Lock [*Ber.*, **62**, 1177 (1929)] has pointed out that aromatic aldehydes containing an hydroxyl group in the para position are characterized by exceptional stability in alkaline solution.

The rate of distillation of veratric aldehyde from the reaction mixture is shown graphically in Curves 1 and 2.[7] The important feature of these curves is that no veratric aldehyde distils over at the beginning of the experiment, a fact which cannot be explained entirely by the time-lag between the formation and distillation of the veratric aldehyde. In a control experiment the distilling flask contained only 2.0 g. of sodium hydroxide and 50 cc. of water at the time that distillation commenced. A very dilute solution of veratric aldehyde was then added by means of a dropping funnel at a rate equivalent to that of its formation, as indicated in the previous experiments, and the contents of the flask were maintained at constant volume. Curve 3 shows the rate of addition of veratric aldehyde to the flask and Curve 4 the amount isolated. The actual lag observed is relatively insignificant, so that in the previous experiment the slow rate of distillation of the veratric aldehyde at the beginning of the reaction must imply an initial slow rate of formation.

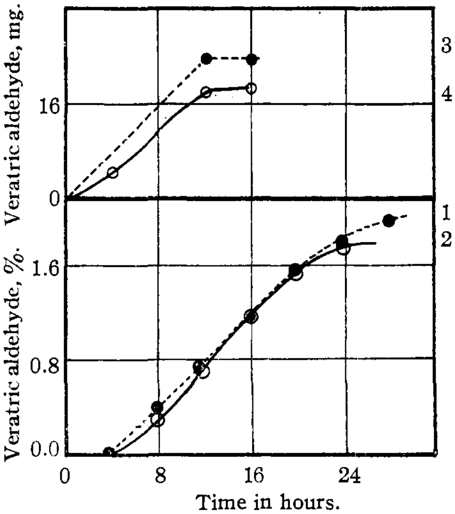

Fig. 1.

Fig. 2.

Fig. 1.—Control experiment: distilling flask contains 3.8% NaOH only at start. Curve 3, rate of addition of veratric aldehyde. Curve 4, rate of distillation of veratric aldehyde.

Fig. 2.—Rate of distillation of veratric aldehyde as formed from methylated lignin sulfonic acids on boiling with 3.8% NaOH. Curve 1, from methylated K L. S. A. (II + III). Curve 2, from methylated K L. S. A. I.

Veratric aldehyde production is therefore the result of a secondary reaction, its rate being governed by some preliminary change, such as the hydrolysis of a sulfonic acid group. This finds further support in the fact that unsulfonated lignins do not give vanillin on treatment with alkali.

Mechanism of Vanillin Formation.—The lignin sulfonic acid fractions from which the vanillin was formed were prepared in such a way as to exclude any possibility of their contamination with a non-ligneous constituent that might give rise to vanillin.[4] This included repeated precipitation from aqueous solution, prolonged dialysis and precipitation in an organic solvent medium. Since vanillin was formed from all fractions in relatively high yields (6.0–8.5%), it follows that the vanillin nucleus forms an integral part of the structure of lignin sulfonic acids, and therefore a part of the structure of the native lignin from which the sulfonic acids were prepared. The various "isolated lignins" must also contain this vanillin nucleus, assuming that their method of preparation is not sufficiently drastic to result in a fission of the lignin molecule. Formation of vanillin in only negligible yields when wood meal or isolated lignins are boiled with alkali does not imply the absence of the vanillin nucleus, but indicates rather some difference in the particular grouping through which the vanillin is attached to the rest of the molecule.

The fact that methylated lignin sulfonic acids yield veratric aldehyde affords conclusive proof that the original lignin sulfonic acid contains a free phenolic hydroxyl group. Moreover, this definitely precludes the possibility of the vanillin hydroxyl resulting from the hydrolysis of an ether linkage as suggested by Kürschner and Schramek.[8] The possibility that the original union existed between one of the unsubstituted carbon atoms in the vanillin and the remainder of the lignin molecule is very slight. However, the formation of the aldehyde group might readily result from the fission of an aliphatic chain under the influence of hot alkali.

Aldehydes are readily formed in alkaline solution from compounds containing the aldol type of grouping

$\underset{\underset{\displaystyle O}{\|}}{-C}-CH_2-\underset{\underset{\displaystyle OH}{|}}{CH}-R$.[9] If vanillin formation depended on the presence of such a secondary hydroxyl group, and this existed pre-

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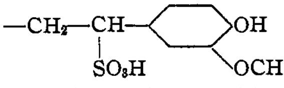
(7) Actually a somewhat higher yield was obtained than is shown, as the combined filtrates (which amounted to several liters) from these precipitates were found to give a further quantity of the benzoyl hydrazone on concentration.

(8) Kürschner and Schramek, *Tech. Chem. Papier-Zellstoff-Fabr.*, **29**, 35 (1932).

(9) Usherwood, *J. Chem. Soc.*, **123**, 1717 (1923).

formed in the lignin sulfonic acid molecule, veratric aldehyde could not result from the *fully methylated* product.

The fact that only sulfonated lignins yield vanillin on boiling with alkali indicates that the presence of the sulfonic acid radical is essential, and that it is adjacent to the vanillin nucleus, for example . In hot alkaline solution, the sulfonic acid radical would be replaced by hydroxyl, giving a product capable of yielding vanillin by a reversed aldol reaction. Under carefully controlled methylation, the sulfonic acid radical in the fully methylated lignin sulfonic acid would remain intact and the latter would then give veratric aldehyde by the same aldol mechanism. The time-lag observed during the formation of the veratric aldehyde in dilute alkaline solution affords considerable support for this conception of a two-stage reaction. Up to the present time, no conclusive evidence has been obtained in support of any one specific mechanism relating to the formation of the sulfonic acid itself from the original lignin.

The Vanillin Content of Lignin.—Methanol lignin,[10] lignin sulfonic acids,[11] Freudenberg lignin,[12] Willstätter lignin[12] and even "native lignin" in spruce[13] show an increase in methoxyl content of about 4% on methylation with diazomethane. Freudenberg *et al.*[14,15] have stated that this cannot be considered as an indication of the presence of a phenolic hydroxyl in lignin since certain aliphatic compounds such as starch behave similarly on treatment with this reagent. However, regardless of whether a phenolic hydroxyl is present or not, it is certain that one type of hydroxyl, peculiar in its reaction toward diazomethane, is common to all lignins. Since the vanillin nucleus is an integral part of the lignin structure, and since in lignin sulfonic acids the vanillin hydroxyl is free, it is presumably this hydroxyl, methylatable with diazomethane, which is common to all lignins.[16]

In relatively few degradation or fission reactions are the end-products recovered in quantitative yield. Thus the 6–8.5% vanillin obtained in the present investigation does not necessarily imply that this is the potential vanillin content of lignin[17] or even that it is the maximum yield that may be obtained. Brauns and Hibbert[10] showed that diazomethane treatment of methanol lignin results in an increase in methoxyl content of 3.7% corresponding to the methylation of one hydroxyl group in a unit of 886. Since at least one vanillin nucleus must be present in each of these building units, the potential vanillin content is 17–18%. This represents the maximum value, since such a lignin unit can contain only one phenolic hydroxyl group. The yield of vanillin obtained thus represents about 40% of the theoretical amount. Although fairly conclusive evidence has been advanced,[10,13,18] that the molecular weight for lignin is actually of the order of 850, it should be pointed out that this value could be doubled, and still fulfil the conditions demanded in its calculation. Such a unit would contain two hydroxyls capable of methylation with diazomethane, only one of which would necessarily be a vanillin hydroxyl. This unit would contain only 8.0–9.0% potential vanillin, and the yield actually obtained would represent almost a quantitative recovery. Although this seems less probable, it would naturally follow from the definite identification in spruce lignin of some other hydroxyl capable of methylation with diazomethane.

Experimental

Formation of Vanillin from Purified Spruce Lignin Sulfonates.—A sample (1.500 g.) of each of the calcium lignin sulfonate fractions described in a previous communication[4] was dissolved in a solution of 12 g. of sodium hydroxide in 50 cc. of water (19.4% by weight). The solution was refluxed for twelve hours in an atmosphere of nitrogen, and the vanillin extracted and estimated by the method previously described by the authors[2] (Table I).

The potassium lignin sulfonates[4] were given the same alkaline treatment but the method of vanillin extraction was modified considerably in order to avoid any secondary hydrolysis or degradation which the lignin fission product might undergo when the mixture was refluxed in acid medium during the trichloroethylene extraction. The alkaline solution was neutralized with hydrochloric acid,

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(10) Brauns and Hibbert, THIS JOURNAL, **55**, 4720 (1933).

(11) King, Brauns and Hibbert, *Can. J. Research*, **13B**, 88 (1935).

(12) Brauns and Hibbert, *ibid.*, **13B**, 78 (1935).

(13) Fuchs and Horn, *Ber.*, **62B**, 1691 (1929).

(14) Freudenberg and Sohns, *ibid.*, **66B**, 262 (1933).

(15) Freudenberg, Sohns and Janson, *Ann.*, **515**, 62 (1935).

(16) Freudenberg *et al.*[15] have recently obtained evidence for the presence of a phenolic hydroxyl in lignin sulfonic acid. By determining the quantity of carbon dioxide liberated by this substance from sodium carbonate, and correcting for the SO_3H content, it was calculated that there is one phenolic hydroxyl in a lignin unit of 500–560. In spite of this evidence, they retain their original view that the phenolic hydroxyl is absent in other lignins and infer that the diazomethane reacts with some non-phenolic group in these products.

(17) This of course applies only to the terminal vanillin nucleus, and has no reference to other nuclei which may, or may not, be present having the same general structure as vanillin, but which are attached to the rest of the molecule at two or more points.

(18) Harris, Sherrard and Mitchell, THIS JOURNAL, **56**, 889 (1934).

and the mixture extracted with ether in a continuous liquid extractor for thirty-six hours. The ether was distilled off under diminished pressure, and the reddish-brown residual oil dissolved in dilute alkali. After acidifying with dilute acetic acid, the light-brown amorphous precipitate which formed was filtered off and the vanillin precipitated from the almost colorless solution by the addition of an aqueous solution of *m*-nitrobenzoic hydrazide, both solutions being at 60°. The vanillin yields, calculated from the weight of the vanillin *m*-nitrobenzoyl hydrazone precipitates, are recorded in Table I.

Anal. Calcd. for vanillin *m*-nitrobenzoylhydrazone: OCH_3, 9.84. Found: Cond. prod. for K L. S. A. I, OCH_3, 9.74; from K L. S. A. (II + III), OCH_3, 9.65; from K L. S. A. II, OCH_3, 9.71.

Following the vanillin extraction, the lignin fission products were filtered off, washed, air-dried and dissolved in dioxane containing about 2% water. The solutions were filtered and absolute dioxane added (about 2–3 volumes) until the solutions became opaque. The mixtures were then added slowly, with stirring, to dry ether, and the light-brown flocculent precipitates were filtered off, washed with ether, then with petroleum ether and dried.

Anal. Fission product from K L. S. A. I: OCH_3, 14.77, 14.64; S, 0.9; ash, 2.7. On ash-free basis, OCH_3, 15.1; S, 0.9. Fission product from K L. S. A. (II + III): OCH_3, 14.50, 14.60; S, 2.0; ash, 3.2. On ash-free basis, OCH_3, 15.0; S, 2.1. Fission product from K L. S. A. II: OCH_3, 14.54, 14.64; ash, 2.4; on ash-free basis, OCH_3, 15.0. Fission product from K L. S. A. III: OCH_3, 14.00, 14.04; S, 2.3; ash, 3.0. On ash-free basis, OCH_3, 14.5; S, 2.4.

Preparation of Crystalline Vanillin from Purified K L. S. A. I.—Eighty grams of sodium hydroxide was added to a solution of 10.00 g. of K L. S. A. I dissolved in 333 cc. of water. The solution was refluxed for twelve hours in a slow current of nitrogen, acidified, extracted with ether for thirty-six hours in a continuous extraction apparatus and the ether evaporated; residue, a reddish-brown product; wt. 0.701 g. This was dissolved in dilute alkali, the solution acidified and the small amount (0.052 g.) of brown amorphous precipitate which formed removed by filtration. The solution was again extracted for thirty-six hours with ether, and the residual product left on evaporation of the ether treated with boiling ligroin (80–90°). The semi-solid extract melted to a dark brown oil in the hot ligroin, and as the vanillin went into solution, a brown solid residue was deposited on the bottom of the flask. The almost colorless ligroin solution was decanted, and this treatment repeated. Pale yellow vanillin crystals separated on cooling; m. p. 77–78°; wt. 0.3482 g. The vanillin remaining in the ligroin solution, together with that remaining in the extracts, was recovered and determined analytically as vanillin *m*-nitrobenzoylhydrazone. An additional 0.0865 g. of vanillin was obtained in this way. The total yield corresponded to 83.5% of that indicated in the small scale experiment with Fraction K L. S. A. I.

After two recrystallizations from ligroin pure vanillin was obtained. Calcd.: OCH_3, 20.4. Found: OCH_3, 20.2; m. p. 80–81°; mixed m. p. (with Mallinckrodt pure vanillin) 80–81°.

Formation of Veratric Aldehyde from Methylated K L. S. A. I.—To 50 cc. of an aqueous solution containing 2.00 g. methylated K L.S.A.I[4] was added 2.0 g. of sodium hydroxide. The solution was placed in a ground glass distilling flask connected with a dropping funnel and a condenser, and distilled at a rate of 60–70 cc. per hour by heating the flask in an oil-bath maintained at 150°. The volume of the solution in the flask was maintained at 50 cc. by adding distilled water dropwise at a rate equal to that of the distillation. The receiver was changed every four hours, and the veratric aldehyde in each fraction precipitated with an aqueous solution of *m*-nitrobenzoic hydrazide. Only a trace of the condensation product formed in the first fraction. Relatively large quantities formed in the second to the sixth fractions, inclusive, but between the seventh and the ninth fractions this quantity steadily fell off. The amount isolated from the first six fractions is shown graphically in Curve 2. The total yield obtained from these fractions, together with the small quantity isolated by concentrating the filtrates amounted to 0.0776 g. of veratric *m*-nitrobenzoylhydrazone, or 0.0391 g. of veratric aldehyde. As the % K + % SO_3H of the methylated lignin sulfonate amounted to 16.4%, this represents a yield of 2.35% veratric aldehyde, calculated on the weight of the "lignin" on a potassium- and SO_3H-free basis.

On similar treatment 1.425 g. of methylated fraction K L. S. A. (II + III) yielded 0.0649 g. of veratric-*m*-nitrobenzoylhydrazone or 0.0327 g. of veratric aldehyde, corresponding to a 2.76% yield on the above basis.

Anal. Veratric *m*-nitrobenzoylhydrazone obtained in above experiment. Calcd., OCH_3, 18.82. Found: OCH_3, 18.4; m. p. 221–222°; mixed m. p. (with *m*-nitrobenzoylhydrazone from pure veratric aldehyde) 221–223°.

A control experiment was carried out using the same apparatus. The distilling flask contained 2 g. of sodium hydroxide dissolved in 50 cc. of water. The rate of distillation was adjusted to 50 cc. per hour (bath temp. 140°) and the volume of the solution in the flask was maintained by constant addition of distilled water. Six hundred cc. of an aqueous solution containing 0.0240 g. of veratric aldehyde was then added at the rate of 50 cc. per hour during the course of twelve hours, and distilled water added at the same rate for a further four hours. The receiver was changed at the end of the fourth, twelfth and sixteenth hours, and the veratric aldehyde determined in each fraction. The results are plotted in Curves 3 and 4. The total recovery amounted to 78.3%.

The authors wish to express their indebtedness to the Howard Smith Paper Mills, Limited, for the award of bursaries during the course of this research, and to Dr. Margaret Greig for practical assistance in some of the analytical work.

Summary

1. Carefully purified spruce lignin sulfonic acid fractions were found to yield vanillin on treatment with hot alkali, thus establishing the presence of the vanillin nucleus in spruce lignin.

2. Methylated spruce lignin sulfonic acids were found to yield veratric aldehyde on treatment with hot alkali, proving the presence of the

phenolic hydroxyl in the original spruce lignin sulfonic acid.

3. Evidence has been obtained that vanillin formation occurs as a two-stage reaction, namely, a preliminary hydrolysis of the sulfonic acid radical followed by an intramolecular fission, the latter change consisting of a "reversed aldol" reaction.

MONTREAL, CANADA RECEIVED NOVEMBER 21, 1935

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY]

On the Mechanism of the Reactions of Metal Enol Acetoacetic Ester and Related Compounds.[1] III. Copper Enolates

BY ARTHUR MICHAEL AND G. H. CARLSON

Cupric enol acetoacetic ester with chlorine gave cupric chloride,[2] but with bromine, iodine,[2] diphenylmethylene chloride[3] and ethylsulfocyanide[4] cuprous derivatives were produced. The non-existence of cupric mercaptide[5] and of solid cupric iodide made the appearance of the cupric compounds impossible. However, it seemed theoretically improbable that the chemical course of cupric enolate reactions should vary so markedly with the chemical character of the reagent and we were, therefore, led to reëxamine the reactions in which the formation of cupric derivatives has been accepted.

Experimental Results

The appearance of cupric chloride in the experiment of Schönbrodt[2] must have been due to an excess of chlorine, since we found that the theoretical amount of cuprous chloride was formed by adding a carbon tetrachloride solution of a mole and a half of chlorine to a suspension of a mole of cupric enol acetoacetic ester at 0° and the same result was obtained on repeating the experiment with a solution of the cupric enolate in boiling carbon tetrachloride. As the second product, α-chloroacetoacetic ester was produced. The experimental details are given in Table V.

At ordinary temperature, acetyl chloride reacted readily with cupric enol acetoacetic ester, in ether or benzene suspension, yielding cuprous chloride, O-acetylacetoacetic and α-chloroacetoacetic esters. Diacetoacetic ester could not be isolated and, if C-acylation occurred, the free ester, not the copper enolate, must be formed, since all the available copper appeared as cuprous chloride.[6] The results of three semi-quantitative experiments are tabulated in Table I.

TABLE I

The cupric enolate was suspended in ether (benzene used in III), acetyl chloride added at room temperature, cuprous chloride filtered off, the solvent removed at reduced pressure from the filtrate and the residual oil analyzed for halogen. An aliquot portion of the oil (total in I) was extracted with alkali, the products worked up in the usual way and the results given under alkaline extraction.

Chloroacetoacetic ester calculated is weight of ester equivalent to halogen present in the residual oil: (II) 0.59057 g. subs. gave 0.1231 g. AgCl; (III) 0.4573 g. subs. gave 0.0763 g. AgCl. The chloro ester regenerated after alkaline extraction in I was not pure. The ester was redistilled and the fraction of b. p. 100–105° at 30 mm. analyzed. Calcd. for $C_6H_9O_3Cl$: Cl, 21.6. Found: Cl, 15.3. The redistilled ester (1.5 g.) and 0.75 g. of thiourea gave 1.1 g. of methylaminothiazole carboxylic ester. The regenerated chloro ester in III (1.5 g.), gave 0.8 g. of the thiazole carboxylic ester.

O-Acetylacetoacetic ester calculated is weight of total residual oil less weight of calculated chloroacetoacetic ester. One gram of the O-acyl ester and 1.3 g. of phenylhydrazine gave 0.75 g. of acetphenylhydrazide in I and II.

Cuprous chloride calculated is amount equivalent to copper enolate used. Percentage of products accounted for is total weight of isolated products divided by total weight of reagents used.

Expt. no.				I	II	III
Copper enolate, g.				30	30	10
Acetyl chloride, g.				11	11	3.7
Time, hrs.				48	50	12
Cuprous chloride, g.			calcd.	9.2	9.2	3.1
			found	9.2	9.2	3.4
Products in filtrate	Total g.			29.5	30.1	9.7
	Alkaline extraction	Sample, g.		29.5	24.0	9.0
		O-Acetylacetoacetic ester, g.		19.8	14.0	6.8
		B. p.	°C.	117–119	119–121	114–116
			mm.	32	33	20
		Chloroacetoacetic ester, g.		7.1	4.3	1.5
		B. p.	°C.	95–103	95–107	
			mm.	30	30	
	Total	O-Acyl ester, g.	calcd.		22.9	7.8
			found	19.8	17.6	7.4
		Chloroacetoacetic ester, g.	calcd.		7.3	1.9
			found	7.1	5.4	1.6
Products accounted for, %				95.5	97	95.5

The action of acetyl chloride upon cupric enol

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[1] THIS JOURNAL, **57**, 159, 165 (1935).

[2] Schönbrodt, *Ann.*, **253**, 168 (1889).

[3] Klages and Fanto, *Ber.*, **32**, 1433 (1899).

[4] Kohler, *Am. Chem. J.*, **22**, 69 (1899).

[5] Klason [*Ber.*, **20**, 3412 (1887)] showed that cuprous mercaptide is formed from cupric sulfate and ethyl mercaptan.

[6] Nef [*Ann.*, **266**, 52 (1891)] found that the alkali-soluble product contained mainly acetoacetic and a little diacetoacetic ester. The neutral product was shown later [*ibid.*, **276**, 200 (1893)] to be O-acetylacetoacetic ester.