

Studies on Lignin Models

The Reaction of Phenyl-Coumaran Structures with Thioglycolic Acid

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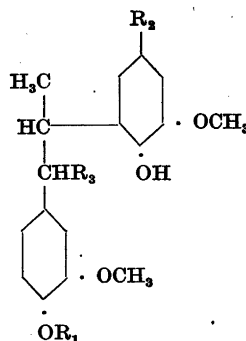
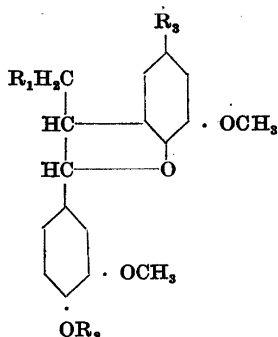
By heating with thioglycolic acid the lignin model substances (III—VI), which contain a 2-phenyl-coumaran structure, are converted into the substances (IX—XIV).

As assumed by Freudenberg and his co-workers the biosynthesis of gymnosperm lignin involves dehydrogenative polymerization of coniferyl alcohol¹, producing three intermediate compounds arising from two coniferyl alcohol molecules being linked together in different ways². These dimeric compounds contain benzyl alcohol and benzyl ether groups; structures which have previously been assumed to be responsible for the sulphonation of lignin³.

One of the dimeric compounds, dehydro-diconiferyl alcohol (I), contains a benzylaryl ether group constituting part of a phenyl-coumaran system. Previously, Freudenberg⁴ had assumed that such structures are building elements of the lignin molecules, and his recent findings support this assumption. That the acid (II)⁵, which contains the phenyl-coumaran structure, is transformed by acid sulphite into the sulphonic acid (VII) by rupture of the benzylaryl ether link⁶ is further support for Freudenberg's assumption. The acid (II) reacts with thioglycolic acid in a similar manner forming compound (VIII)⁶.

The acid (II) contains a carboxyl group which may influence the stability of the benzylaryl ether link, and we have therefore studied the reaction of thioglycolic acid with model substances containing the coumaran structure but no carboxyl group: namely dehydro-diisoeugenol (III), dihydro-dehydro-diisoeugenol (IV) and their methyl ethers (V and VI).

Heating these substances for 1.5—2 hours with thioglycolic acid containing hydrochloric acid afforded in practically quantitative yield thioglycolic acid adducts which were difficult to purify as they were syrups from which crystalline derivatives could not be obtained. For this reason the analytical values obtai-

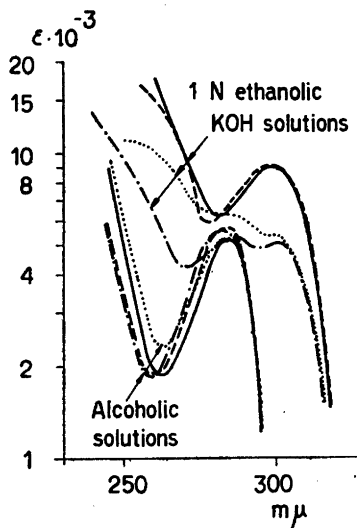


	R ₁	R ₂	R ₃
I	OH	H	CH:CH:CH ₂ OH
II	H	CH ₃	COOH
III	H	H	CH:CH:CH ₃
IV	H	H	CH ₂ :CH ₂ :CH ₃
V	H	CH ₃	CH:CH:CH ₃
VI	H	CH ₃	CH ₂ :CH ₂ :CH ₃

	R ₁	R ₂	R ₃
VII	CH ₃	COOH	SO ₃ H
VIII	CH ₃	COOH	SCH ₂ COOH
IX	H	CH ₂ :CH ₂ :CH ₃	»
X	H	CH(SCH ₂ COOH):CH ₂ :CH ₃	»
XI	H	CH ₂ :CH(SCH ₂ COOH):CH ₃	»
XII	CH ₃	CH(SCH ₂ COOH):CH ₂ :CH ₃	»
XIII	CH ₃	CH ₂ :CH(SCH ₂ COOH):CH ₃	»
XIV	CH ₃	CH ₂ :CH ₂ :CH ₃	»

ned on powdery derivatives (benzylthiuronium salts or acetates) did not agree well with those calculated. However, they showed that one molecule of the hydrogenated substances (IV) and (VI) reacted with about one molecule of the thioglycolic acid, and that the other, (III) and (V), reacted with about two molecules of the acid.

Fig. 1. The absorption curves for the thioglycolic acid adducts.
 The adduct from (III) —————
 (IV) - - - - -
 (V)
 (VI) - . . . -



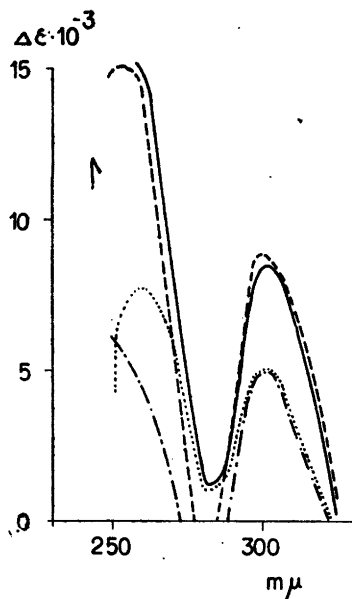


Fig. 2. The $\Delta\epsilon$ -curves for the thioglycolic acid adducts.

The adducts from (III) —————
 (IV) - - - - -
 (V) ······
 (VI) - · - · -

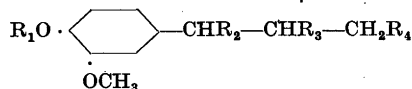
The structures of the adducts were elucidated by a spectrophotometric examination. In alcohol the model substance (III) has λ_{\max} 274 $m\mu$, ϵ_{\max} 20 000⁷. The hydrogenated derivative (IV) has λ_{\max} at about the same wave-length, 281 $m\mu$; ϵ_{\max} for that derivative, however, is 5 400, which is much lower than the value for (III)⁷. The difference in ϵ_{\max} may be attributed to the fact that only (III) has an aliphatic double bond conjugated with a benzene nucleus. The spectra of all the thioglycolic acid adducts have λ_{\max} at 282—284 $m\mu$ and ϵ_{\max} about 5 500 in alcoholic solution (Fig. 1). Thus, the curves of the products are very similar to the curves of the hydrogenated derivative (IV) but diverge from that of (III). It was concluded, therefore, that the aliphatic double bonds of (III) and (V) had disappeared during the reaction by addition of thioglycolic acid.

If the benzylaryl ether group in the model substances reacted as that in the acid (II) the adducts should contain a new phenolic group. The number of phenolic groups in the adducts has been estimated by the spectrophotometric method introduced by Aulin-Erdtman⁸. The absorption spectra of neutral and alkaline solutions of the adducts are shown in Fig. 1, and in Fig. 2, the so-called $\Delta\epsilon$ -curves. All the $\Delta\epsilon$ -curves have a maximum at about 300 $m\mu$, which is characteristic for phenols which do not contain a double bond conjugated with the benzene ring. The value of $\Delta\epsilon$ at this maximum is for the adducts from the methylated model substances (V) and (VI), about 5 000. This value is about the same as that found by Aulin-Erdtman⁸ for monophenols and therefore these adducts contain one phenolic group in the molecule. The corresponding values for the adducts from the other model substances (III and IV) is about 9 000 showing that they contain two phenolic groups.

Thus, this evidence shows that during the reaction with thioglycolic acid a new phenolic group is formed.

To sum up, the thioglycolic acid most probably reacted with the benzyl-aryl ether links of the four compounds and with the aliphatic double bonds of (III) and its methyl ether (V). The products obtained may, therefore, have the structures (IX—XIV).

When thioglycolic acid is added to the aliphatic double bond in (III) or its methyl ether (V) two isomers can be formed: (X) and (XI) from (III), and (XII) and (XIII) from (V). Holmberg⁹ has shown that when styrene reacts with thioglycolic acid the isomer containing the $S \cdot CH_2 \cdot COOH$ group in the β -position to the phenyl group resulted. We have found that when thioglycolic acid was added to *isoeugenol* two isomers, the benzylthiuronium salt of one having m.p. 120—1° and that of the other having m.p. 130—1°, were formed. The first of these compounds was also obtained from 1-(3-methoxy-4-hydroxyphenyl) propanol (XV) by heating with thioglycolic acid, and as it is known that a hydroxyl group in a benzyl alcohol can be substituted by a $S \cdot CH_2 \cdot COOH$ group in this manner^{9,10} it is reasonable to assume the compound is the α -derivative (XVII), and the other isomer the β -derivative (XIX). Only one compound was obtained from the methyl ether of *isoeugenol*, and as it was not identical with the product from 1-(3,4-dimethoxyphenyl) propanol (XVI), the α -derivative (XVIII), it must therefore be the β -derivative (XX). It appears possible from the above evidence that the thioglycolic acid adducts obtained from (III) and its methyl ether (V) are mixtures of (X) and (XI), and of (XII) and (XIII) respectively.



	R ₁	R ₂	R ₃	R ₄
XV	H	OH	H	H
XVI	CH ₃	OH	H	H
XVII	H	SCH ₂ COOH	H	H
XVIII	CH ₃	SCH ₂ COOH	H	H
XIX	H	H	SCH ₂ COOH	H
XX	CH ₃	H	SCH ₂ COOH	H
XXI	H	H	H	SCH ₂ COOH

Thioglycolic acid was also added to the double bond of eugenol but the reaction was slow in comparison with that of *isoeugenol*. The acid obtained was not identical with the α -derivative (XVII) or the β -derivative (XIX). This evidence and the fact that the adduct contained no C-methyl group show that it was the γ -derivative (XXI).

If lignin contains phenyl-coumaran structures of the type examined in this investigation, it is probable that they will react with thioglycolic acid during the preparation of lignothioglycolic acid from lignin. As mentioned above

phenolic elements are formed in this reaction. Thus it is possible to estimate the frequency of such coumaran structures in lignin from the number of phenolic groups formed during the preparation of thioglycolic acid, *e. g.* the difference in the number of phenolic groups in lignothioglycolic acid and that of lignin.

According to Aulin-Erdtman¹¹ about one seventh of the phenylpropane monomers in lignothioglycolic acid contains a phenolic group. It is known that lignin in the native state also contains phenolic elements, but their frequency is not known. For that reason the number of phenolic groups formed cannot be estimated, but, the low frequency in lignothioglycolic acid shows that the number produced during the preparation cannot be high. It is probable, therefore, that the frequency of phenyl-coumaran structures of the above-mentioned type is rather low in lignin.

EXPERIMENTAL

A mixture of the model compound (m g), thioglycolic acid (t g), water (w ml) and 2N HCl (c ml) was heated at 100° for h hours. A large amount of water was added to the product and the resultant precipitate washed well with water, dissolved in ether and separated into acidic (a g), and phenolic or neutral material (b g) by bicarbonate. The following compounds were examined.

1-(3-Methoxy-4-hydroxyphenyl) propanol (XV). m 0.6, t 1.5, w 1.5, c 0.1, h 1.5, b 0.02. The acidic reaction product was neutralized with 2 N NaOH and a solution of benzylthiuronium chloride (800 mg) in water (1.2 ml) was added. The oily precipitate, which solidified overnight, was dissolved in hot alcohol. The insoluble benzylthiuronium salt (20 mg) of thioglycolic acid was collected and hexane was added to the filtrate. The benzylthiuronium salt (860 mg) of S- α -guaiacylpropyl-thioglycolic acid (XVII) crystallized in needles, m.p. 120–1°. Yield 63%. (Found: OCH₃ 7.3; S 14.9; C 57.0; H 6.19; N 6.2. Calc. for C₂₀H₂₆O₄S₂N₂ (422): OCH₃ 7.3; S 15.2; C 56.8; H 6.16; N 6.6.)

This salt (500 mg) was covered with ether and decomposed by addition of dilute HCl. The free acid (250 mg), m.p. 52–53.5°, crystallized very slowly. The acid was converted to its sodium salt and crystallized from alcohol by addition of ether. (Found: Na 8.28. Calc. for C₁₇H₁₈O₄SNa (278): Na 8.14.)

1-(3,4-Dimethoxyphenyl) propanol (XVI). m 0.42, t 1.0, w 1.0, c 0.1, h 1.5, b 0.02. The acidic product was converted to the benzylthiuronium salt. The oily precipitate, which solidified immediately, crystallized from alcohol. The benzylthiuronium salt (550 mg) of S- α -veratrylpropyl-thioglycolic acid (XVIII) crystallized in fine needles, m.p. 149.5–150°. Yield 59%. (Found: OCH₃ 14.2; S 14.3; C 58.0; H 6.65; N 7.0. Calc. for C₂₁H₂₈O₄S₂N₂ (438): OCH₃ 14.2; S 14.6; C 57.5; H 6.39; N 6.4.)

Isoeugenol. m 15, t 17, w 15, c 1, h 1.5, a 16, b 2. The acidic product was neutralized with 2 N NaOH and kept in a refrigerator overnight. The crude Na-salt (4.8 g) of S- α -guaiacylpropyl-thioglycolic acid (XVII) separated. On concentrating the mother liquor to half its volume, a further quantity (0.25 g) of the same material was obtained. The sodium salt was crystallized from alcohol giving the analytically pure salt (3.25 g), from which the benzylthiuronium salt was prepared. No m.p. depression was observed on admixture with the product obtained from 1-(3-methoxy-4-hydroxyphenyl) propanol. The free acid regenerated from this salt also showed the same m.p. and mixed m.p. with that obtained from the propanol.

The mother liquor was diluted with an equal amount of water and a solution of benzylthiuronium hydrochloride (15 g) in water (50 ml) added. The oily salt which separated was washed with water, dissolved in chloroform (100 ml). The solution was dried and kept in a refrigerator. The benzylthiuronium salt (6.6 g) of S- α -guaiacylpropyl-thioglycolic acid separated from the solution and after washing with chloroform the salt was obtained in pure state.

The chloroform solution was concentrated to dryness, the residual syrup dissolved in octyl alcohol (70 ml) and was kept in the refrigerator. The crude benzylthiuronium salt (4.39 g) of S- β -guaiacylisopropyl-thioglycolic acid (XIX) precipitated and after crystallization from acetone-ether gave the pure salt (3.9 g) in thin plates, m.p. 130–1°. It showed marked depression on admixture with the benzylthiuronium salt of S- α -guaiacylpropyl-thioglycolic acid. (Found: OCH₃ 7.1; S 15.1; C 56.7; H 6.27; C-CH₃ 3.84, 3.62. Calc. for C₂₀H₂₆O₄S₂N₂ (422): OCH₃ 7.3; S 15.2; C 56.8; H 6.16; C-CH₃ 6.16.)

A large amount of petroleum ether was added to the mother liquor and the oil which separated was dissolved in acetone, a small amount of petroleum ether added and the solution kept in a refrigerator for two weeks. The crystals which separated were crystallized from alcohol-petroleum ether giving a further quantity (450 mg) of benzylthiuronium salt of S- α -guaiacylpropyl-thioglycolic acid. Yields: α 36, β 12 %.

Isoeugenol methyl ether. m 4.5, t 4.8, w 3.8, c 0.3, h 3, a 5.4, b 0.25. The acidic product was converted to its benzylthiuronium salt in the usual way. The salt obtained directly as a crystalline mass was dissolved in alcohol and precipitated by hexane. The precipitate (4.4 g), m.p. 133–4°, was crystallized from alcohol. The benzylthiuronium salt of S- β -veratrylisopropyl-thioglycolic acid (XX) was obtained in plates, m.p. 135–6°. It showed marked depression on admixture with the benzylthiuronium salt of the α -acid (XVIII). Yield 42 %. (Found: OCH₃ 13.9; S 14.5; C 57.7; H 6.72; N 6.5. Calc. for C₂₁H₂₅O₄S₂N₂ (438): OCH₃ 14.2; S 14.6; C 57.5; H 6.39; N 6.4). None of the α -isomer could be detected.

Eugenol. m 11, t 13, w 15, c 3, h 7, a 5, b 6.5. The acidic product was converted in the usual way to the benzylthiuronium salt, which was dissolved in hot alcohol. On cooling, the benzylthiuronium salt (2 g) of S- γ -guaiacylpropylthioglycolic acid (XXI), m.p. 144.5–145.5°, crystallized. Ether was added to the mother liquor giving a further quantity (2.5 g) of the same material having the same m.p. Yield 40 %. (Found: OCH₃ 7.8; S 14.9; C 56.6; H 6.39; C-CH₃ 0.8. Calc. for C₂₀H₂₆O₄S₂N₂ (422): OCH₃ 7.3; S 15.2; C 56.8; H 6.16; C-CH₃ 0.0. None of the salt of the β -isomer (XIX) could be detected.

S- γ -guaiacylpropyl-thioglycolic acid (0.28 g) (XXI) of m.p. 69–70° was obtained from this salt (0.5 g) in the manner described above for (XV). (Found: S 12.3. Calc. for C₁₂H₁₆O₄S (256): S 12.5.)

Dihydro-dehydro-diisoeugenol (IV). m 5, t 15, w 10, c 1, h 2, a 7.26, b 0.11. The acidic product was acetylated with pyridine and acetic anhydride. The acetylated derivative of (IX) was obtained as a white amorphous powder, m.p. 60–64°. (Found: OCH₃ 11.7; S 6.7. Calc. for C₂₆H₃₂O₅S (504): OCH₃ 12.3; S 6.4.)

Dehydro-diisoeugenol methyl ether (V). m 5, t 20, w 25, c 3.5, h 1.5, a 6.8, b 0.08. The acidic product was converted in the usual way to its benzylthiuronium salt, which was purified by precipitation from a chloroform solution by addition of petroleum ether. The salt begins to sinter at about 70° and melts at 100–110°. (Found: OCH₃ 10.4; S 14.1. Calc. for C₄₁H₅₂O₅S₄N₄ (856): OCH₃ 10.9; S 14.9.)

Dehydro-diisoeugenol (III). m 5, t 20, w 25, c 3.5, h 1.5, a 6.1, b 0.05. The acidic product was converted to its benzylthiuronium salt, which was purified by precipitation from an abs. alcoholic solution by petroleum ether and washed with ether. M.p. 69–80°. (Found: OCH₃ 7.9; S 14.3. Calc. for C₄₀H₅₀O₅S₄N₄ (842): OCH₃ 7.4; S 15.2.)

Dihydro-dehydro-diisoeugenol methyl ether (VI). m 0.7, t 2.1, w 1.4, c 0.14, h 1.5, a 0.86, b 0.02. The acidic product was analyzed directly. (Found: OCH₃ 21.6; S 7.3. Calc. for C₂₃H₃₀O₅S (434): OCH₃ 21.4; S 7.4.)

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