ready hydrolysis and oxidation, particularly in wet ether solution, yielding aniline salts of the corresponding sulfonic acids.

AMES, IOWA

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE UNIVERSITY OF ILLINOIS]

OPTICALLY ACTIVE DIAZO COMPOUNDS
III. A CRYSTALLINE, ALICYCLIC DIAZO ESTER

BY FORREST EVERETT KENDALL[1] WITH WILLIAM ALBERT NOYES

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Levene and La Forge[2] first discussed the possibility of an asymmetric aliphatic diazo group. They obtained a crystalline diazo compound that very probably contained such a group, but they could not demonstrate this, as the compound contained other asymmetric carbon atoms.

In 1918 Levene[3] assumed optically active diazo groups and a Walden inversion in the treatment of an aliphatic amino group with nitrous acid. Some years before, Potter[4] and one of us had observed a Walden inversion, involving the shift of a methyl group, on treatment of an alicyclic amino acid with nitrous acid.

In 1920 Marvel and Noyes[5] attempted unsuccessfully the preparation of an aliphatic diazo compound in which the only asymmetric carbon atom was the one attached to the diazo group.

Levene and Senior and Levene and Mikeska[6] had also been working on the problem and the latter obtained an active compound with a small rotatory power. In the latter paper they reaffirm their belief in the optical activity of the diazo group, based on the different products obtained by the action of nitrous acid on glucose-aminic and manosaminic esters. As they did not isolate the two isomeric diazo compounds, such a conclusion does not seem to be entirely valid.

Chiles and Noyes[7] obtained six optically active diazo compounds in which the asymmetric carbon atom was combined with the diazo group. Levene and Mikeska[8] have confirmed their work in part, but have found some differences.

In the discussion of Levene and in the earlier discussion by the senior

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[1] Abstract from a thesis presented to the Graduate Faculty of the University of Illinois in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

[2] Levene and La Forge, *J. Biol. Chem.*, **21**, 347 (1915). Dr. Levene and the senior author of this paper discussed the possibility of such asymmetry in March, 1915.

[3] Levene, *J. Biol. Chem.*, **36**, 89 (1918).

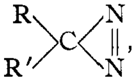
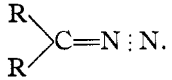
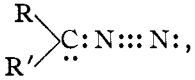
[4] Noyes and Potter, THIS JOURNAL, **34**, 1067 (1912).

[5] Marvel and Noyes, *ibid.*, **42**, 2259 (1920).

[6] Levene and Mikeska, *J. Biol. Chem.*, **45**, 592 (1921); **52**, 485 (1922).

[7] Marvel with Noyes, THIS JOURNAL, **42**, 2259 (1920). Chiles and Noyes, *ibid.*, **44**, 1798 (1922).

[8] Levene and Mikeska, *J. Biol. Chem.*, **55**, 795 (1923).

author, it has been assumed that the optical activity of the diazo compounds may be explained either by the Curtius, , or the Angeli-Thiele formula,  $\begin{matrix}R\\R\end{matrix}\!\!>C{=}N:N$. If atoms held together by a pair of shared electrons are only potentially, and not actually, positive and negative,[9] the optical activity of diazo compounds cannot be explained by the Curtius formula. The work of Staudinger[10] on the addition of phosphines to aliphatic compounds has demonstrated that the Angeli-Thiele straight-chain formula is more probable. We may write this formula  $\begin{matrix}R\\R'\end{matrix}\!\!>\underset{\cdot\cdot}{C}:N:::N:$, indicating that the pair of electrons between the carbon and nitrogen atoms is shared by the two atoms, forming a covalence, while the lower pair belongs exclusively to the carbon and forms a polar valence corresponding to the polar valence of the acid radical in aromatic diazonium salts. Such a compound might be optically active in the same manner as the optically active sulfonium compounds of Smiles, of Pope and Peachey and of Pope and Neville,[11] in which one of the valences is a similar polar valence on the sulfur atom.[12] This formula bears some resemblance to the formula $R_2{=}C::N::N::$, proposed by Langmuir,[13] but the latter formula ignores the very important distinction between shared and unshared electrons in their ability to balance the positive charges of the nuclei of atoms. This distinction will be discussed in a future paper.

The pair of unshared electrons on the carbon atom may be the reason why aliphatic diazo compounds are so sensitive to hydrogen ions and why they racemize so easily.

The rotation of the active diazo compounds thus far obtained is so small that some critics think that it may be due to impurities which it is impossible to remove from such unstable substances. While we are convinced that this criticism is not warranted, it seems very desirable to se-

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[9] See Noyes, THIS JOURNAL, **45**, 2959 (1923); *Trans. Faraday Soc.*, **19**, 476 (1923); *Bull. soc. chim.*, **34**, 418 (1924); *Ber.*, **57**, 1236 (1924).

[10] Staudinger, *Helvetica Chim. Acta*, **5**, 75 (1922).

[11] Smiles, *J. Chem. Soc.*, **77**, 1174 (1900). Pope and Peachey, *ibid.*, **77**, 1072 (1900). Pope and Neville, *ibid.*, **81**, 1552 (1902).

[12] It should be noticed that the polar valence of the carbon atom assumed here is negative, while that of the sulfur atom in the sulfonium compounds is positive. This is because either four unshared electrons or four pairs of shared electrons are required in the outer shell of a carbon atom to balance the positive charge of the nucleus, while six unshared electrons or six pairs of shared electrons are required to balance the charge of the nucleus of a sulfur atom. This important principle, which has not been explicitly stated before, will be made the subject of a subsequent paper.—W. A. Noyes.

[13] Langmuir, THIS JOURNAL, **42**, 285 (1920).

cure compounds with a higher rotatory power and also compounds that can be purified by crystallization. We have obtained such compounds from both *cis*- and *trans*-aminocamphonanic acid. As these substances contain two asymmetric carbon atoms, it is necessary to secure the diazo compound from both forms in order to establish the optical activity of the diazo group. Thus far we have secured only a small amount of the diazo compound from the *trans* form, and the evidence is incomplete, but it seems desirable to report now on the work already finished.

The decomposition of the two aminocamphonanic acids with nitrous acid has been very thoroughly investigated by Skinner and Noyes,[14] and the products are partly different, but there is no conclusive proof that the diazo compounds are an intermediate step in the decomposition. Even if they are such a step, as seems probable, they may racemize or undergo inversion during their decomposition.

Noyes and Coss[15] have shown that a diazo compound is an intermediate in the formation of the bishydrazone of camphonanic ester discovered by Noyes and Taveau.[16] We find that two molecular proportions of the diazo compound described in this paper decompose practically quantitatively on standing a short time at ordinary temperatures, giving one molecular proportion of the bishydrazone and one of nitrogen. The formula for the diazo compounds given here indicates that the reaction is closely analogous to the coupling reactions of aromatic diazonium compounds. When benzene diazonium chloride couples with dimethylaniline, a hydrogen ion from the latter combines with the chloride ion and the outer nitrogen atom of the diazonium group attaches itself to the position left vacant, the diazonium group rearranging at the same time to the azo group: $C_6H_5\underset{\overset{\cdot\cdot}{\mathrm{Cl}}}{N}:::N + H\cdot C_6H_4N(CH_3)_2 = C_6H_5{-}N{=}N{-}C_6H_4N\text{-}(CH_3)_2 + HCl.$

In the formation of the bishydrazone one molecule of the diazo compound loses a molecule of nitrogen and the outer nitrogen atom attaches itself in the place of the diazo group. The compound then rearranges to the bishydrazone, $R{=}\underset{\cdot\cdot}{C}:N:::N: + R{=}\underset{\cdot\cdot}{C}:N:::N: = R{=}C::N:N::C{=}R + N_2$. This formula also gives a very simple explanation for the Walden rearrangements referred to above. The substituting atom or group attaches itself to the unshared electrons of the carbon atom. This will give anoptical inversion.

In addition to the work of Taveau and Coss referred to, Ross[17] also attempted the preparation of the diazo compound from *cis*-aminocamphonanic acid, but the desired compound was not isolated.

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[14] Skinner and Noyes, THIS JOURNAL, **39**, 2692 (1917). Skinner, *ibid.*, **45**, 1498 (1923).

[15] Noyes and Coss, *ibid.*, **42**, 1280 (1920).

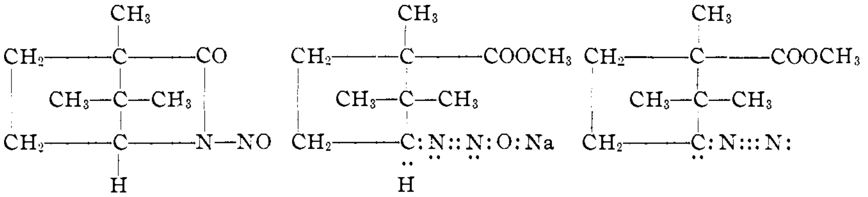
[16] Noyes and Taveau, *Am. Chem. J.*, **32**, 287 (1904).

[17] Ross, *Master's thesis*, University of Illinois, 1925.

In the present work it was finally obtained in a crystalline form as follows.

Two g. of the nitroso-anhydride dissolved in 50 cc. of anhydrous ether was treated with 0.25 molecular proportion of sodium methylate in methyl alcohol at —20°. The yellow color of the nitroso solution gradually changed and at the end of an hour a deep red solution showing a blue fluorescence in certain lights was obtained.

Our interpretation of the reaction is that the sodium atom of the sodium methylate adds to the oxygen of the nitroso group and the methoxy group to the carbon of the carbonyl. This is accompanied by the formation of a double union between the two nitrogen atoms. Sodium hydroxide then splits off, a triple union forms between the nitrogen atoms and a polar valence on the carbon atom that has lost hydrogen.



The relations of the electrons concerned with the formation of the diazo group are indicated in the last two formulas.

The solution was washed with water to remove alcohol and sodium hydroxide, both of which catalyze the decomposition of the diazo compound, and was dried by cooling to —80° to freeze out the water. The anhydrous salts usually employed for drying liquids cause a rapid decomposition of the diazo compound. The solution was concentrated to a volume of 5 cc. under reduced pressure in a stream of dry air, free from carbon dioxide. Carbon dioxide also causes rapid decomposition. Upon cooling this solution to —80°, rouge-red, hexagonal crystals separated. The solvent was removed with an inverted filter and the crystals were dried on a porous plate and placed in a vacuum desiccator. When they were allowed to warm to 10° they gradually melted with the evolution of nitrogen and later formed a white solid that was shown to be the bishydrazone of Noyes and Taveau; 0.2209 g. of the diazo compound was placed in a stoppered tube and allowed to warm to room temperature. The crystals melted with evolution of nitrogen and at the end of 48 hours had solidified, giving a white, waxy solid; m. p., 45°; loss in weight, 0.0172 g., or 7.78%. This indicated a 90% conversion into the bishydrazone and a 10% conversion into nitrogen-free unsaturated compounds. Unsaturation was shown by the action toward potassium permanganate. The solid after two crystallizations from a mixture of ether and petroleum ether melted at 99°, the value given by Taveau for the bishydrazone.

Because of the instability of the diazo compound, the crystals were kept, and all work with them was carried out in a cold room where the temperature was below freezing. The crystals melted quite sharply at 30° when heated rapidly in a capillary tube. The material was analyzed for diazo nitrogen by decomposing it with dil. sulfuric acid and measuring the nitrogen evolved. The analysis of the first crystals obtained gave 11.7% of nitrogen; calcd., 14.3%. This indicated a diazo content of 82%. By recrystallizing five times from 5cc. portions of ether, an analysis of 13.9% of nitrogen, indicating 97.5% of the diazo compound, was obtained.

The specific rotation of the diazo compound was obtained in two ways. The crystalline solid was weighed and dissolved in ether and the rotation of the solution measured. As the impurities contained in the compound, principally the bishydrazone, had very low rotations, the rotation observed was considered to be due entirely to the diazo compound and a correction made according to the diazo content; 0.2124 g. containing by analysis 82% of diazo compound, dissolved in 25 cc. of ether gave a rotation of +3.28°; $[\alpha]_D$ = +336°; corrected for diazo content, $[\alpha]_D$ = 405°; 0.2174 g. containing by analysis 93% dissolved in 25 cc. of ether gave a rotation of +3.36°; $[\alpha]_D$ +386°; corrected for diazo content, $[\alpha]_D$ = 415°. The diazo compound was analyzed for carbon and hydrogen in the ordinary manner.

TABLE I

SUMMARY OF ANALYSES

Preparation	Carbon, %	Hydrogen, %	Nitrogen, %	$[\alpha]_D$	$[\alpha]_D$ corr. to % of diazo
1	..	..	11.7	+376°	+405°
2	..	..	13.3	+386°	+415°
3	61.13	7.60	13.9	+367°	+378°
4	..	..	12.9	+405°	+450°
5	..	..	13.2	+362°	+400°
6	61.9	8.91	13.3	....	....
7	62.0	8.53	13.8	+396°	+410°
8	..	..	13.4	+384°	+409°
Calcd.	61.2	8.16	14.3	....	....
				Av.	+409°

As the values obtained for the specific rotation of the diazo compound varied considerably, due probably to the gradual decomposition of the compound in the ether solution, a second method of obtaining the specific rotation was devised. The rotation of an ether solution was determined and the solution then analyzed by introducing a measured portion into a mercury eudiometer and decomposing with methylsulfuric acid. The volume of the gas evolved was measured and corrected for the vapor pressure of ether. By keeping the temperature low, so as to reduce the vapor pressure of the ether, accurate values were obtained. As the solution used was more impure than that obtained from the crystalline substances, the rotation of the solution after decomposition was subtracted from the rotation observed.

TABLE II

SUMMARY OF ROTATIONS OF DIAZO SOLUTION

Preparation	Diazo ester per cc., g.	Obs. $[\alpha]_D$	Obs. $[\alpha]_D$ after decompn.	$[\alpha]_D$
1	0.0172	+ 8.10°	+0.67°	+432°
2	.0143	+ 6.82°	+0.70°	+427°
3	.0284	+13.15°	+1.04°	+426°
4	.0203	+10.31°	+1.28°	+445°
			Av.	+433°

In order to decide definitely whether this high rotation is due in part to the diazo group or was due entirely to the other asymmetric carbon atom it was necessary to obtain the diazo compound from the isomeric *trans*-aminocamphonanic acid. This compound does not form an anhydride, so the method used for the *cis* compound could not be used. Attempts to use von Pechmann's[18] method, by the action of alkali upon the nitroso derivative of an acylamine, failed because we were unable to prepare the nitroso derivative of either the benzoyl or formyl compound. Werner[19] has shown that primary alkyl ureas give nitroso derivatives upon treatment with nitrous acid and that these decompose with alkali giving diazo compounds. $\mathrm{CH_3{-}NH{=}CO{-}NH_2 \rightleftarrows CH_3{-}NH{-}C(OH){=}NH \xrightarrow{HNO_2} CH_3{-}N(NO){-}C(OH){=}NH \xrightarrow{KOH} CH_2{=}N{\equiv}N + CO_2 + NH_3}$. *sec*-Butyl urea and other secondary alkyl ureas investigated did not give nitroso derivatives with nitrous acid but decomposed, giving the corresponding isocyanates in 50% yields. The disubstituted secondary alkyl ureas, however, gave nitroso derivatives that decomposed with alkali to give the desired diazo compounds.

The disubstituted urea from methyl-*trans*-aminocamphonanate was obtained in two ways.

First, by treating the ethereal solution obtained by the action of nitrous acid upon the monosubstituted urea with methyl-*trans*-aminocamphonanate the disubstituted urea was obtained. This substance is insoluble in ether, dilute acids and cold alcohol. It is somewhat soluble in hot alcohol and crystallizes from it in long, silky needles; m. p., 305° (corr.). Second, it was prepared by treating an ethereal solution of the amine ester with an equivalent amount of phosgene in toluene. After standing for two hours the precipitated "di-urea" and amine hydrochloride are filtered off. The hydrochloride is removed by washing with water and the "di-urea" recrystallized from hot alcohol. The material prepared in this way had the same melting point as that described above.

Anal. Subs., 0.1503: CO_2, 0.3492; H_2O, 0.1230. Calcd. for $C_{21}H_{36}O_5N_2$; C, 63.85; H, 9.09. Found: C, 63.35; H, 9.08.

One g. of the "di-urea" was suspended in ether and treated with nitrous anhydride to form the nitroso derivative. The ether solution of the nitroso derivative was treated with sodium methylate at —20° and allowed to stand for one hour. At the end of that time the solution was washed with cool water and dried by cooling to —80° and filtering off the ice that had been frozen out. The rotation of the solution for sodium light was determined and found to be +1.28°. The solution was analyzed for diazo nitrogen by the method already described. Five cc. of the solution gave 1.8 cc. of nitrogen over ether at 745 mm. and 0°. This is equivalent to 0.0116 g. of diazo ester, or a concentration of 0.0023 g. per cc.

After decomposition the rotation of the solution was +0.48°. This gave a specific rotation $[\alpha]_D = +558°$ for the solution of the diazo compound. As the solution after decomposition had a rotation considerably above any obtained in later determinations, it was thought that the difference between the rotation of the solution before and after decomposition would give a more accurate measure of the rotation of the compound; $[\alpha]_D = +348°$ (corr.).

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[18] von Pechmann, *Ber.*, **27**, 1888 (1894).

[19] Werner, *J. Chem. Soc.*, **115**, 1093 (1919).

Two more preparations of the diazo solution were made in the same way; $[\alpha]_D = 415°$ and $430°$.

The rotatory dispersion of ether solutions of both the *cis* and *trans* forms of the diazo compound were measured. The lines of the mercury-vapor arc were used as a source of light. Measurements were made in a very sensitive, three-shade universal polarimeter.

Table III

Average Values for Specific Rotation of Diazo Esters

Wave length, Å.	6152	5780	5461	4900	4350
From *cis* compound	+260°	+510°	+785°	−80°	−590°
From *trans* compound	+240°	+535°	+810°	−85°	−475°

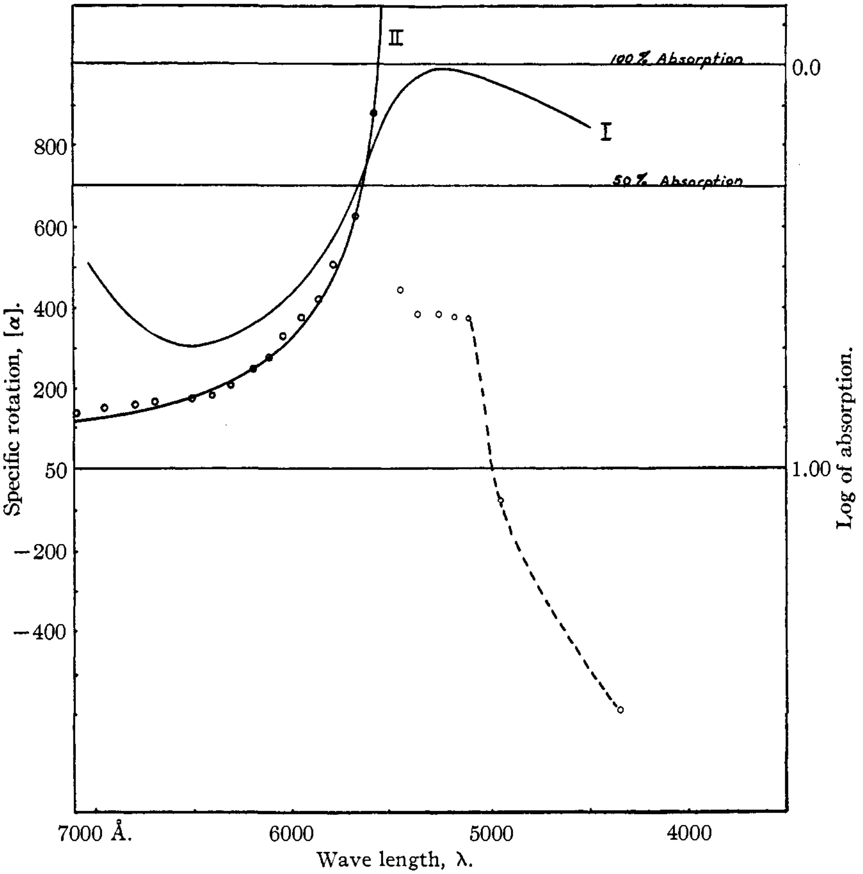

Fig. 1.—Rotatory dispersion of methyl γ-diazo-camphonanate. I. Absorption curve; $C = 0.0014$ g./cc. in ether. II. Calculated from $[\alpha] = 26/(\lambda^2 - 0.53^2)$. Circles; experimental values of $[\alpha]$.

According to Lowry and Walker,[20] those terms of Drude's equation, $[\alpha] = [K_0/(\lambda^2-\lambda_0^2)] + [K_1/(\lambda^2-\lambda_1^2)] + \ldots$, that contain the character-

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[20] Lowry and Walker, *Nature*, **113**, 565 (1924).

istic frequencies of any particular group in a molecule represent the contribution of that group to the rotation of the compound. The absorption of the diazo compound was measured in a spectrophotometer; it was shown that there was an absorption band that centered at about λ = 5300 Å. This band is without question due to the diazo group. The rotatory dispersion curve (Fig. 1) for the red and yellow part of the spectrum agreed very closely with the curve $[\alpha] = K/(\lambda^2-\lambda_0^2)$, where $\lambda_0 = 0.53$ micron and $K = 26$, indicating that this part of the curve is due largely to the asymmetry of the carbon atom bearing the diazo group. (See Possibility 3 in the discussion below.) The deviation of the curve from that calculated may represent the effect of the other asymmetric carbon.

Discussion

So far as the primary purpose of our investigation is concerned, the results must be considered as still inconclusive. There seem to be three possibilities.

1. The rotation caused by the asymmetry of the carbon atom bearing the diazo group may be small, as it is with all similar groups thus far studied. The determinations of the rotation, especially that of the *trans* compound, are not sufficiently accurate to settle this point.

2. The diazo group may racemize as soon as it is formed and the rotation may be due exclusively to the carbon atom bearing the methocarboxyl group. The fact that Skinner found, in part, the same products from the action of nitrous acid on the *cis*- and *trans*-amino esters, points somewhat to this conclusion.

3. Because of the other asymmetric carbon atom the *cis* form of the diazo compound may be formed both from the *cis* anhydride and the *trans* "di-urea." The dispersion curves point to this conclusion, as mentioned above.

Skinner found by the decomposition of the *cis*-aminocamphonanic acid 40 parts of hydroxy to 60 parts of unsaturated esters; from the *trans* ester, 60 of hydroxy and 40 of unsaturated esters. The decomposition of our diazo compound prepared from the *cis* anhydride has given approximately the same proportions of the two classes of products that Skinner found from the *cis*-amino ester. Also, it has given none of the *cis*-camphonolic ester which he found among the products from the decomposition of the *trans* compound. These facts point to either the first or third possibility. A decision between these may be possible by studying the decomposition products of the diazo compound from the *trans* "di-urea." This will be undertaken, but the problem is extremely difficult and it may not be possible to secure enough of the necessary materials.

Summary

1. A crystalline diazo compound has been obtained by treating the nitroso derivative of the anhydride of *cis*-aminocamphonanic acid with sodium methylate and crystallizing the product from ether at —80°.

2. The compound melts at 30°. Its specific rotation, $[\alpha]_D$, is about 420°.

3. The rotatory dispersion of the compound is large, ranging from +260° through +785° to —590°. The dispersion agrees closely with the values calculated from Drude's equation.

4. A diazo compound has also been prepared, in small amounts and in a less pure condition, from the "di-urea" *trans*-aminocamphonanic acid. Its properties agree, roughly, with those of the diazo compound from the *cis* acid but the evidence on this point is incomplete.

5. It has been pointed out that an electronic interpretation of the Angeli-Thiele formula for the aliphatic diazo compounds shows a close analogy between these compounds and the aromatic diazonium compounds.

6. The diazo compound passes almost quantitatively into the bis-hydrazone of camphonanic acid on standing for a short time. This reaction is closely analogous to the coupling reactions of aromatic diazonium compounds.

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[CONTRIBUTION FROM THE BUREAU OF CHEMISTRY, UNITED STATES DEPARTMENT OF AGRICULTURE]

PECTIC ACIDS

BY E. K. NELSON

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F. Ehrlich and R. V. Sommerfeld, in their exhaustive investigation on the constitution of the pectic substances of the sugar beet,[1] apply the term "pectin" to the material, usually called "protopectin," which is not soluble in cold water, but is dissolved by hot water.

According to Ehrlich and Sommerfeld, this "pectin" is hydrolyzed by hot water into "hydropectin," which can be separated by 70% alcohol into soluble araban and the calcium-magnesium salt of pectic acid which is not dissolved. On treating this salt with hydrochloric acid in the cold and precipitating with alcohol they obtain the free pectic acid $C_{43}H_{62}O_{37} + 10H_2O$ which, after hydrolysis for several hours with 2% hydrochloric acid on the water-bath, yields methyl alcohol, acetic acid, arabinose, galactose, an insoluble digalacturonic acid (A) and a soluble digalacturonic acid (B). They conclude that beet pectic acid is a triacetyl-arabino-galacto-dimethoxy-tetragalacturonic acid. The digalacturonic acids are formed from two molecules of galacturonic acid by the elimination of water between the aldehyde groups and hydroxyl groups of the adjacent molecule. The insoluble modification (A) has the formula $C_{10}H_{14}O_8(COOH)_2H_2O$.

Wichmann and Chernoff in their method for determining pectic acid

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[1] Ehrlich and Sommerfeld, *Biochem. Z.*, **168**, 263–323 (1926).