

gated starch molecules. From the work reported in this paper it seems likely that the structure of the large pectin molecule is similar to that of certain starches. On the other hand, Schneider and Fritsch¹⁹ claim that pectin has a "macro molecule" bound with main valences only and is not an aggregate of the chemical units. The observations made at this Laboratory are not in favor of their contention.

There is no information available on the relative reducing power of polygalacturonic acids containing different numbers of galacturonic acid anhydride residues. The formula proposed for polygalacturonic acid by Morell, Baur and Link²⁰ is generally accepted and if true would indicate a direct proportionality between the number of molecules in the polymer and its reducing power. In case of starch the presence of non-reducing aldehyde groups has been assumed²¹ but without conclusive evidence to that effect. The low reducing power observed in purified pectins is believed by the author to be a characteristic property of the pectin molecule. In spite of many attempts made at this Laboratory, no pectin preparation entirely free of reducing power has been obtained as yet. The significance of the natural

(19) Schneider and Fritsch, *Ber.*, **69**, 2540 (1936).

(20) Morell, Baur and Link, *J. Biol. Chem.*, **105**, 1 (1934).

(21) See a discussion of this matter in Hanes, *The New Phytologist*, **36**, 101 (1937).

reducing power of pectins will be the subject of a later contribution.

Assuming that the aldehydic reducing groups are tied up or masked in some manner in higher polymers of galacturonic acid, this would only modify and not eliminate the postulated secondary structure. Until evidence of this fact is presented, it seems more likely that the aggregates of polygalacturonic acid molecules are held together by means of secondary valence attractions not affecting the reducing power of the terminal aldehydic groups of the chemical polygalacturonic acid units.

Summary

1. When pectin solutions are enzymatically decomposed the viscosity decreases more rapidly than corresponds to the increase in reducing power.

2. The viscosity of pectin solutions can be reduced by heat without any increase in the reducing power. This heat-degenerated pectin is decomposed by enzymes at the same velocity as the original unheated pectin solution.

3. These results are explained by postulating a structure $[(G)_m]_n$ for pectin in which $(G)_m$ is a polygalacturonic acid. The n units of polygalacturonic acids form a secondary aggregate which is mostly responsible for the viscosity of pectin.

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The Action of Chlorine on Thiocyanates

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This paper is contributed as a report of an investigation carried out recently in this Laboratory on the development of new methods for synthesis of sulfonyl chlorides. The recent interest in the chemotherapy of sulfanilamide and related compounds has stimulated a demand for new and improved methods of synthesizing sulfonyl chlorides. We have reported previously on a method of formation of chlorides of this type by interaction of chlorine with isothiouras,² and also the

action of chlorine on other types of sulfur combinations.³

Observations on the chemical action of anhydrous chlorine on the lower alkyl thiocyanates have been made by Cahours,⁴ Riche,⁵ and James,⁶ but none of the workers identified a sulfonyl chloride among the various reaction products described. Cahours mentioned obtaining by the chlorination of methyl thiocyanate a heavy yellow oil which solidified in contact with ammonia. If the experimental conditions employed by him

(1) Sterling Professorship of Chemistry Research Assistant, 1937-1938.

(2) Johnson and Sprague, *THIS JOURNAL*, **58**, 1348 (1936); *Science*, **83**, 528 (1936); Sprague and Johnson, *THIS JOURNAL*, **59**, 1837 (1937); **59**, 2439 (1937).

(3) Johnson and Douglass, *THIS JOURNAL*, **60**, 1486 (1938).

(4) Cahours, *Ann.*, **61**, 96 (1847).

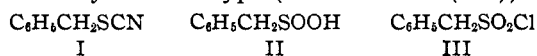
(5) Riche, *ibid.*, **92**, 357 (1854).

(6) James, *J. Chem. Soc.*, **51**, 268 (1887).

were not strictly anhydrous, this oil may have contained some methyl sulfonyl chloride, but it was undoubtedly a mixture of reaction products. A careful search of the literature has failed to disclose other instances in which a sulfonyl halide may have been produced directly from a thiocyanate by treatment with a halogen.

We have found that aliphatic thiocyanates can be transformed readily into sulfonyl chlorides in excellent yields by the action of aqueous chlorine at low temperatures. The reaction has proved to be one of very practical technique in most of the applications made of the chlorination process. In addition to the sulfonyl chlorides, cyanogen chloride (CNCl) is also a product of the chlorination reaction. Cahours,⁴ Riche,⁵ and James,⁶ all reported obtaining crystals of the trimolecular form of this chloride (CNCl)₃.

The behavior of benzyl thiocyanate (I) on chlorination was very puzzling until it was discovered that there was an intermediate formation of benzylsulfinic acid (II), which was only slightly soluble in water and comparatively unreactive toward chlorine at the low temperature of the reaction. This formation of benzylsulfinic acid is very interesting because it affords probably the easiest method yet available for the preparation of this unstable compound, and also because of the light it throws on the mechanism of the reaction leading to the formation of the sulfonyl chloride (III). Benzyl sulfinyl chloride, C₆H₅CH₂SOCl, is a possible intermediate of this reaction, and could be the precursor of either benzylsulfinic acid, II, or benzylsulfonyl chloride, III. This will be discussed more fully in a future paper from this Laboratory. In none of our chlorination experiments with thiocyanates have we obtained any evidence of the formation of intermediate sulfur compounds of the *sulfenic* acid type (—SOH or —S(OH)).⁷



In a patent application now pending,⁸ based partially on this work, examples are given of the preparation of fifteen different sulfonyl chlorides by the action of aqueous chlorine on thiocyanates, and of *n*-butoxyethoxyethyl sulfonyl bromide by the action of aqueous bromine on the corresponding thiocyanate. The reaction is of general application whether the nucleus linked to the —SCN group is substituted or unsubstituted, and whether

it is alkyl, aralkyl, aryl, alicyclic or heterocyclic in nature.

Experimental Part

Methylsulfonyl Chloride, CH₃SO₂Cl.⁹—Twelve and one-half parts of methyl thiocyanate (CH₃SCN) and 100 parts of water are mixed in a vessel immersed in an ice-bath. The mixture is agitated thoroughly while chlorine gas is bubbled into the solution at a rate such that the temperature is kept at 5° or lower. The passage of the chlorine is continued until the yellow color of the reaction mixture shows that an excess of chlorine is present. This takes about two to two and one-half hours. The oil which separates is extracted with ether, the resulting ether solution washed first with sodium bisulfite solution and then with sodium bicarbonate solution, and finally dried over anhydrous calcium chloride. The methylsulfonyl chloride is distilled at reduced pressure and boils at 55° under 11 mm. This chloride is converted easily to methyl sulfonic acid (CH₃SO₂OH) by acid hydrolysis, and to the corresponding sulfonamide (CH₃SO₂NH₂) by the action of ammonia;¹⁰ yield 75%.

Ethylsulfonyl Chloride¹¹ (C₂H₅SO₂Cl).—Twenty grams of ethyl thiocyanate (C₂H₅SCN) suspended in 200 cc. of water is stirred vigorously at a temperature of 0–5° during the addition of chlorine gas at a rate of 2–3 liters per hour. Treatment with chlorine is continued until a permanent greenish-yellow color is produced, indicating an excess of the halogen. Air is then blown gently through the mixture to remove the excess of chlorine, after which an oil separates and is extracted with ether. After washing with sodium bisulfite and sodium bicarbonate solutions, and drying the ether extract over calcium chloride, the ethylsulfonyl chloride was obtained in a yield of 79%. It was identified by its boiling point (71–72° at 20 mm.) and refractive index.

Cyanogen chloride (CNCl) was identified in the water layer after the removal of the sulfonyl chloride by extraction with ether. The solution was heated and a gentle stream of air was blown through it and into 5 cc. of aniline oil. The aniline was then washed with dilute sodium hydroxide to remove the phenylcyanamide formed and the alkaline solution, after neutralization of the excess of sodium hydroxide, was shaken with a few drops of benzoyl chloride. Benzoyl phenylcyanamide precipitated and after recrystallization from alcohol melted at 124–125°. The melting point of this product mixed with an authentic sample was not lowered.

Benzylsulfinic Acid (C₆H₅CH₂SOOH), and Benzylsulfonyl Chloride from Benzyl Thiocyanate (C₆H₅CH₂SCN).—

(9) Billeter, *Ber.*, **38**, 2019 (1905).

(10) Helferich and Gaüchtel [*ibid.*, **71**, 712 (1938)] and Helferich and Mittag [*ibid.*, **71**, 1480 (1938)] have found this sulfonyl chloride (CH₃SO₂Cl) is of practical use in preparing characteristic derivatives for identifying certain carbohydrates and α-amino acids. They write, however, as follows regarding the experimental difficulties in preparing pure methanesulfonyl chloride: "In the preparation of methanesulfonyl chloride from the sodium salt of methanesulfonic acid by the action of phosphorus pentachloride, it is very difficult to separate the sulfonyl chloride from the phosphorus oxychloride. Only by repeated fractional distillation can this be accomplished, and then with great losses."

(11) Gerhardt and Chancel, *Jahresberichte*, **434** (1852); Spring and Winssinger, *Ber.*, **15**, 447 (1882).

(7) Tonnies, *J. Biol. Chem.*, **122**, 27 (1937).

(8) Serial No. 201728, "Sulfonyl Chlorides," Filed in U. S. Patent Office April 13, 1938; Application allowed March 7, 1939.

Benzyl thiocyanate (10 g.), freshly crystallized and finely pulverized, was suspended in 200 cc. of water and chlorinated as described above at a temperature of 0–2°. In two to three hours the contents of the flask consisted of a yellow pasty mixture which was filtered through an ice cold Büchner funnel. The solid was washed with ice water to remove chlorine hydrate and sucked as dry as possible. The filtrate gave a heavy precipitate with barium chloride and smelled strongly of cyanogen chloride. The latter was identified by the formation of benzoyl-phenylcyanamide as described above.

The solid product of reaction was spread on filter paper to dry in the air, but after three to four hours of exposure it had decomposed with the evolution of sulfur dioxide and had absorbed into the filter paper. From the paper were extracted unchanged starting material, and a white solid which contained sulfur but no halogen or nitrogen. This was insoluble in acid or alkali, evolved sulfur dioxide on heating and melted at 108–109°. Since these properties are those that might be expected of a disulfone or a disulfoxide, and since the melting point corresponded to that recorded for $C_6H_5CH_2SOSOCH_2C_6H_5$,¹² the original reaction product that spontaneously decomposed was suspected of being benzyl sulfinic acid, $C_6H_5CH_2SOOH$.

To establish this conclusion the chlorination experiment was repeated and the white solid formed was treated immediately with sodium bicarbonate solution, in which most of it dissolved. The residue, consisting chiefly of unchanged benzyl thiocyanate, was removed by washing with ether. The alkaline solution was then treated with 1 cc. of benzyl chloride and heated on the steam-bath for one hour. On cooling, colorless crystals separated having a melting point of 151–152°, which corresponds with the melting point recorded for dibenzylsulfone.

Anal. Calcd. for $C_{14}H_{14}O_2S$: S, 13.02. Found: S, 13.22,

In another experiment 10 g. of benzyl thiocyanate was chlorinated at 0–2° to apparent saturation, then the temperature was raised to 15–20° and the chlorination continued. The products of the reaction were $C_6H_5CH_2SO_2Cl$ in 45% yield, benzyl chloride, cyanogen chloride, and positive evidence of the formation of sulfate ion by interaction with barium chloride to form barium sulfate. Again when chlorination of 10 g. of pure benzyl thiocyanate was carried out at 20–30°, 9.33 g. of impure benzylsulfonyl chloride melting at 84–88° was obtained. This smelled distinctly of benzyl chloride and the aqueous filtrate gave a heavy sulfate ion test.

To determine whether the benzyl chloride and sulfate ion resulted from the action of chlorine water on the benzyl thiocyanate or on the benzylsulfinic acid, 10 g. of benzyl thiocyanate was chlorinated at 0–2° and the white solid product was treated quickly with sodium bicarbonate solution. After extracting with ether to remove all undissolved material from which was recovered unchanged thiocyanate and a few milligrams of benzylsulfonyl chlo-

ride, the solution was acidified with an excess of hydrochloric acid and immediately chlorinated at 20–25° to saturation. The product consisted of 5.75 g. of benzylsulfonyl chloride which melted at 92° without further purification. Although the water in which the original chlorination was carried out reacted strongly for sulfate ion, the final filtrate after removing the sulfonyl chloride gave only a slight cloudiness with barium chloride.

The amount of benzyl chloride and sulfate formed seemed to be increased if the benzyl thiocyanate was impure or if the temperature during chlorination was not kept under rigid control. A chlorination experiment carried out in 80% acetic acid solution resulted in the formation of benzyl chloride almost to the complete exclusion of benzylsulfonyl chloride.

The Formation of Benzylsulfonyl Chloride by Chlorination of Benzyl Isothiourea Hydrochloride.—This hydrochloride was chlorinated under conditions identical to those employed in the treatment of benzyl thiocyanate. There was no evidence of the formation of benzylsulfinic acid and benzylsulfonyl chloride which melted at 92° without purification was obtained in 76% yield. Barium chloride solution formed only a slight precipitate in the aqueous filtrate.

Chlorination of Phenyl Thiocyanate (C_6H_5SCN).—This aromatic thiocyanate is much more resistant to the action of chlorine than the aliphatic compounds. Chlorination for eight hours under the usual experimental conditions gave a product that contained less than half the calculated amount of chlorine required for benzenesulfonyl chloride. Chlorination for even sixty hours at room temperature failed to yield a product free of the starting material. Some benzenesulfonyl chloride was formed, however, for when the product was treated with aniline and the reaction mixture extracted with sodium hydroxide, benzenesulfonyl anilide was obtained by acidifying the alkaline solution.

Summary

1. Organic thiocyanates can be employed with success for the synthesis of sulfonyl chlorides.
2. Chlorination of such thiocyanates in aqueous suspension and at low temperatures leads to a transformation of $-SCN$ to $-SO_2Cl$.
3. Benzyl thiocyanate can be changed by chlorination at low temperatures into benzylsulfinic acid. On chlorination in aqueous suspension at higher temperature, benzylsulfonyl chloride is formed in excellent yield.
4. The question of the mechanism of the different chlorination reactions thus far reported from this Laboratory will be discussed in a future paper.

(12) Fromm and de Seixas Palma, *Ber.*, **39**, 3315 (1906).