

Furfuryl Mercaptan

An Improved Preparative Method

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It has been observed that 2-furfuryl alcohol reacts exceptionally smoothly with equimolar amounts of thiourea and hydrochloric acid in aqueous solution to give furfuryl *isothiourea*. This reaction is utilized as a step in a rapid and reliable method for the preparation of 2-furfuryl mercaptan. The yield was 60 %.

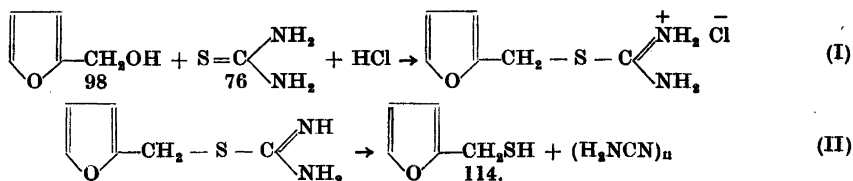
The reaction mechanism is briefly discussed.

Two syntheses of 2-furfuryl mercaptan have previously been reported in the literature. According to one method, which is only briefly described in a patent issued to Staudinger and Reichstein¹, furfural is treated with ammonium hydrosulphide and the resulting *bis*-furfuryl disulphide is subsequently reduced to the mercaptan. Neither physical properties nor yield were stated. Attempts by the present author to reproduce the method gave exceedingly small yields.

The other method was reported in 1929 by Kirner and Richter². They prepared furfuryl *isothiuronium* chloride from furfuryl chloride and thiourea. The product was hydrolyzed without being isolated, and the mercaptan was obtained in 33 % yield. Although this is a useful method of quite general applicability to mercaptans, it is, however, less convenient in the present instance. The preparation of furfuryl halides is somewhat laborious, because the furane ring is extremely sensitive to hydrogen halides. Preparation of furfuryl chloride in quantity was in fact only achieved in 1928, when Kirner³ applied Darzens's method of halogenation⁴, *i.e.* treatment of furfuryl alcohol with thionyl chloride in pyridine solution. It is the present author's experience, however, that appreciable resinification always occurs, even when great care is taken; the yield varies, and the pure furfuryl chloride is exceedingly unstable. It decomposes within a few days.

In experiments made during the years 1942—1943, it was observed that the intermediate halide could conveniently be omitted, and the mercaptan obtained in 60 % yield by direct action of furfuryl alcohol on thiuronium

chloride in aqueous medium (I), followed by thermal decomposition of the liberated furfuryl isothiourea (II).



The direct formation of isothiuronium salts from alcohols was first reported by Stevens⁵ in 1902, and it was later employed by Johnson and Sprague⁶ as an intermediate step in the synthesis of alkylsulphonyl chlorides. It had not so far been applied to the preparation of mercaptans. The method described in detail in the experimental section has been in frequent use during the last war. It was found convenient and reliable. Furfuryl mercaptan is a major component in roast coffee aroma, and the synthetical product was used in extremely small concentrations for aromatization of artificial coffee.

After the war a paper by Frank and Smith⁷ appeared, in which these investigators independently applied essentially the same method to the preparation of a number of acyclic and carbocyclic mercaptans. The experimental conditions reported by Frank and Smith were far more rigorous than those described in the present paper. They used a large excess of hydrogen halide (as concentrated hydrochloric or hydrobromic acid), 3 moles per mole thiourea, and refluxed the reaction mixture for 9 hours. The formation of furfuryl isothiuronium halide on the other hand takes place spontaneously in not very concentrated aqueous solution, when equimolar amounts of the reactants in equation (I) are mixed at room temperature. The reaction is strongly exothermic, and it is imperative to control the process by suitable cooling in order to avoid excessive discoloration. It is not quite certain, whether the process goes to completion under these circumstances, but subsequent refluxing, as recommended by Frank and Smith, did not increase the yield, on the contrary it was greatly reduced, and a large amount of tar was obtained. The large excess and much higher concentration of hydrochloric acid used by Frank and Smith is strongly contraindicated because of the sensitivity of the furan ring to mineral acids.

Frank and Smith decomposed the thiuronium compound (reaction II) by refluxing the neutralized reaction mixture for two hours. A more convenient method in the present case was steam distillation of the neutralized mixture. The free furfuryl isothiourea decomposed readily at 100° and the mercaptan, which is practically insoluble in water, separated from the distillate as a colourless heavy oil of high purity. The yield was uniformly 60 % based upon furfuryl alcohol.

As already pointed out by Frank and Smith⁷ two different mechanisms may explain the general process exemplified by reaction (I). Either there is a direct condensation of the alcohol with the *iso*-thiuronium ion



or an intermediate halide is formed

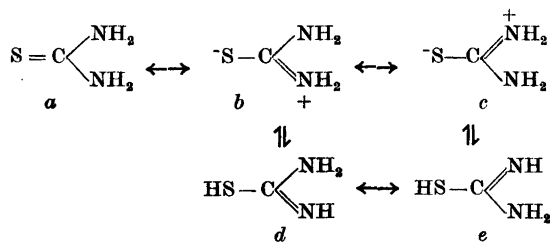


In mechanism (A) the hydrogen halide acts only as an acid, in mechanism (B) it has the additional function as a halogenating agent.

Frank and Smith obtained some evidence in favour of (B) in that better yields were generally obtained of the various mercaptans, when hydrochloric acid was replaced by hydrobromic acid. This is easily understood on the basis of mechanism (B), since it is well known that alkyl bromides form easier than alkyl chlorides from an alcohol and hydrogen halide. Such difference would not be expected if the hydrogen halides acted only in their capacity as acids as in mechanism (A). On the other hand Frank and Smith found that octyl mercaptan could be prepared, although in minute yield, when using sulphuric acid in stead of hydrogen halides. They considered this observation to be in favour of mechanism (A). It is, however, well known that alkyl sulphates are powerful alkylating agents and may act as intermediates similarly to the alkyl halides, *i.e.* the observation is — *mutatis mutandis* — equally well compatible with mechanism (B).

Regarding the particular process involving furfuryl alcohol it appears at a first view that mechanism (A) must obtain, since the reaction between the alcohol and thiuronium chloride proceeds smoothly without stoichiometric excess of hydrochloric acid as used by Frank and Smith. It must, however, be remembered that thiuronium chloride is almost completely hydrolyzed in aqueous solution^{8,9} and consequently there is free hydrochloric acid available for the formation of intermediate furfuryl chloride. From this argument therefore it is impossible to decide about the mechanism.

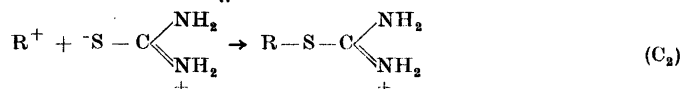
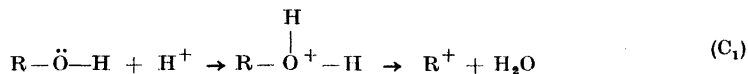
Since very little thiuronium ion exists in aqueous solution, it may be doubtful, whether it is really this ion that reacts, or it is free thiourea. Modern views on the structure of this substance may be summarized in the following scheme



X-ray diffraction methods¹⁰ and Raman spectroscopy¹¹ have revealed that in the crystalline state thiourea is a planar symmetrical resonance hybrid of the structures $a \longleftrightarrow b \longleftrightarrow c$, the latter method giving considerable support to the ionic structures. The same formulation may be applied to the substance in solution. In older work on the absorption in ultraviolet it was concluded

that the substance has the *isothiurea* structure $d \leftrightarrow e$, whereas a was discarded¹². It is also claimed¹³ that the tautomerism between $a \leftrightarrow b \leftrightarrow c$ on one hand and $d \leftrightarrow e$ on the other hand has been confirmed by osmometric measurements.

It seems reasonable to suppose that the reaction (I) is of ionic nature and the following mechanism, which is closely related to mechanism (A), is suggested



Obviously decisive evidence can only be derived from a kinetic examination of the reaction, but the following observations are compatible with the mechanism:

i. The reaction proceeds satisfactorily only in acid solution. The effect of the acid probably is to favour the dissociation of the alcohol (C₁).

ii. It was observed that, contrary to the findings of Frank and Smith⁷ for other mercaptans, the course of the reaction and the yields were identical, when using hydrochloric acid and hydrobromic acid respectively. This suggests that only the hydrogen ion participates in the reaction, and that an intermediate halide formation is unlikely in this particular instance.

iii. S-alkyl *isothiureas* are known to be much stronger bases than thiourea itself. This is manifested in the mechanism. Thiourea appears in its basic form, whereas the product is formulated as an *isothiuronium* ion (C₂).

Attempts were made to prepare various structurally related primary mercaptans according to the "mild" method described in the experimental section. The alcohols used as starting materials were tetrahydrofurfuryl, allyl, benzyl, *n*-butyl and cinnamic alcohol. There was no spontaneous rise of temperature, and after a time corresponding to at least 60 % reaction of furfuryl alcohol most of the alcohols could be recovered unchanged. It therefore seems true that furfuryl alcohol reacts exceptionally smoothly with thiourea, and that in most other cases either a much longer time of reaction or the rigorous conditions employed by Frank and Smith⁷ are required. The slow reaction of tetrahydrofurfuryl alcohol indicates that the double bond is essential. On the other hand the apparent failure of allyl alcohol to react shows that something more than the unsaturation is needed to accelerate the reaction. A possible explanation may be found in the electron distribution in the furan ring. There is a relatively high electron density on the ring carbon atom in position 2, and this negative charge may activate the alcohol group (step C₁).

EXPERIMENTAL

380 g (5 moles) thiourea were dissolved by gently heating in a mixture of 405 ml hydrochloric acid (5 moles) and 500 ml water. The exact concentration of the hydrochloric acid had previously been determined by titration. The solution was cooled to room temperature and 490 g (5 moles) furfuryl alcohol (b.p.₇₆₀ 170°) was quickly added

with stirring. In 1–2 minutes the reaction started. It was accompanied by a considerable evolution of heat and the temperature was held below 60° by cooling the reaction vessel under the water tap. When the reaction slowed down, cooling was discontinued, and the dark green but clear solution was left over night for completion of reaction. Then a solution of 225 g sodium hydroxide, containing 5 moles NaOH, in 250 ml water was added. A heavy brown oil precipitated, consisting of furfuryl isothiurea, which was already partly decomposed to the mercaptan. The flask was equipped with a condenser for steam distillation. The mercaptan separated from the distillate as a colourless heavy oil. The dried yield was 340 g or approximately 60 %. The product distilled uniformly at 84° C at 65 mm Hg and had $n_D^{20} = 1.533$ in accordance with literature². It could be distilled at atmospheric pressure without destruction. The boiling point was 160° at 759 mm Hg.

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