Kinetics of Desulphuration of Ethylthiourea in Sodium Hydroxide studied by a Radiochromatographic Method

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Decomposition of ethylthiourea in aqueous sodium hydroxide has been studied by a radiochromatographic method. The main process is second-order desulphuration, $EtNHCSNH_2 + OH^- \longrightarrow C_2H_5NHC{=}N + HS^- + H_2O$, but a small amount of thiocyanate is formed as a by-product. Rate constants at 90, 100, and 110° and derived activation parameters have been obtained. Possible mechanisms are discussed taking into account the fact that desulphuration is three times faster for thiourea than for ethylthiourea, under the same conditions.

PREVIOUS studies[1] have shown that phenylthiourea dissociates into hydrogen sulphide and phenylcyanamide under alkaline conditions, into thiocyanic acid and aniline over a wide range of pH, but more readily at higher values, and into phenyl thiocyanate and ammonia but this reaction becomes appreciable only in the presence of strong acid. All monosubstituted thioureas are desulphurized; unlike phenylthioureas, methylthiourea is more easily decomposed by alkali than by acid because of the presence of a positive substituent.[2] Previously[3] we studied the kinetics of desulphuration of thiourea in alkaline solution by means of radiochromatography. The same method has now been used to study the desulphuration of ethyl[^{35}S]thiourea in sodium hydroxide at 90, 100, and 110°.

EXPERIMENTAL

Solutions.—Ethyl[^{35}S]thiourea (2·9 mg; 37 μCi) was isotopically diluted with inactive ethylthiourea in H_2O (5 ml) to give a 0·2M solution (specific activity 37 μCi mmol^{-1}). 0·2M-NaOH was prepared by diluting a solution of CO_2-free NaOH (C. Erba Normex) with water twice distilled under nitrogen. This solution was kept and samples taken under nitrogen. The concentration of NaOH and the absence of CO_2 in the final solution were checked. Equal volumes (0·05 ml) of the equimolecular solutions of ethylthiourea and NaOH were transferred, under nitrogen, to Teflon containers (0·15 ml), then sealed in hermetically-closed steel containers. These solutions were heated in a thermostatted bath (±0·2°).

Preliminary experiments were performed in Teflon containers (1·5 ml) with equal volumes (0·5 ml) of 0·2M-solutions of inactive ethylthiourea and CO_2-free NaOH in order to establish which conditions are best for the elution and separation of the different products and their qualitative identification, and the R_F values.

Chromatographic Separation.—The reacted solution (10 μl) was deposited on a Whatman No. 1 paper strip (1·5 × 35 cm) and treated with 1M-zinc acetate (0·02 ml) in order to insolubilize the sulphide ion present in solution. The other products were then eluted in compact spots by the ascending method with n-butanol–ethanol–1M-ammonium acetate (20 : 5 : 10). Ethylthiourea was detected with the Roche reagent[4] and thiocyanates with a 0·2M-ferric chloride. By eluting the pure products, or a mixture of them, with the same eluting solution the following R_F values were obtained: ZnS = 0·00, NaSCN = 0·47, $EtHNCSNH_2$ = 0·75, $EtNH_3SCN$ = 0·57 (this last substance was not observed among the products). The quantitative determination of ^{35}S-labelled compounds was performed by measuring their radioactivity in contiguous areas of the strip with a Geiger counter fitted with a 10 × 15 mm slit.

pH Measurements.—The pH values of reacted solutions were measured directly in the Teflon containers after cooling the solution at 20° under nitrogen using a Metrohom glass electrode type EA 125 U (for pH = 0—14) connected to a Polymetron 42 D pH meter reading 1/50 pH unit.

Nitrogen was freed from oxygen by washing with Fieser's solution.[5]

RESULTS AND DISCUSSION

The radiochromatographic determinations of the active species formed in the alkaline desulphuration of ethylthiourea at 90, 100, and 110° gave the results reported in the Table. After 25 h reaction in 0·1M-NaOH ethylthiourea is transformed into thiocyanate and sulphide (*ca.* 0·5 and 14%, 1·75 and 23%, and 3·2 and 38% at 90, 100, and 110°, respectively). Although the reactions are competitive, the transformation into sulphide is, under these experimental conditions, largely predominant, and that into thiocyanate may, to a first approximation, be ignored.

By analogy with thiourea,[3] the alkaline desulphuration of ethylthiourea may be considered as a second-order reaction, first order in ethylthiourea and in sodium hydroxide. The normal second-order rate

$$EtNHCSNH_2 + OH^- \longrightarrow C_2H_5NHC{=}N + HS^- + H_2O \quad (1)$$

equation applies. The assumption that $[EtNHCSNH_2] = [OH^-]$ seems reasonable owing to the fact that NaOH is a strong base in very dilute solution and that its dissociation at 90—110° is higher than at room temperature.

The good linearity of the plots of $(a - x)^{-1}$ against t (Figure 1) for the three temperatures investigated confirms this assumption, and demonstrates that the omission of the transformation of ethylthiourea to thiocyanate does not alter the results substantially and that the values of the rate constants (Table) may be considered as reliable. Furthermore, the ratio between the rate constants at 90, 100, and 110°, k_{100}/k_{90} 1·90, k_{110}/k_{100} 1·89, is constant. Also plots of log k and log k/T against $1/T$ (Figure 2) are linear.

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[1] S. Mehta and H. Krall, *J. Indian Chem. Soc.*, 1935, **12**, 635.

[2] R. H. Sahasrabudhey and R. Singh, *J. Indian Chem. Soc.*, 1953, **30**, 499.

[3] G. Marcotrigiano, G. Peyronel, and R. Battistuzzi, *J.C.S. Perkin II*, 1972, 1539.

[4] J. Roche, *Biochem. Biophys. Acta*, 1954, **14**, 71.

[5] L. F. Fieser, *J. Amer. Chem. Soc.*, 1924, **46**, 2639.

Kinetics of desulphuration of ethyl[^{35}S]thiourea (EtTu*) (0·1M) in NaOH (0·1M)

		Molar concentrations ($\times 10^5$)			pH	10^5k/
T/°C	t/h	$[S^{*-2}$	$[S^*CN^-]$	[EtTu*]	at 20°	l mol^{-1} s^{-1}
90	0			10,000	12·96	
	5	307	18	9675	12·93	1·75
	10	630	25	9344	12·89	1·86
	15	926	32	9042	12·86	1·88
	20	1119	46	8835	12·82	1·74
	25	1386	50	8564	12·79	1·78
						1·81 Average
100	0			10,000	12·96	
	5	566	32	9402	12·91	3·33
	10	1101	51	8848	12·85	3·43
	15	1618	85	8297	12·79	3·57
	20	2048	108	7844	12·72	3·57
	25	2319	175	7506	12·66	3·35
						3·45 Average
110	0			10,000	12·96	
	5	1000	86	8914	12·80	6·17
	10	1881	177	7942	12·64	6·44
	15	2543	235	7222	12·48	6·32
	20	3311	250	6439	12·33	6·87
	25	3828	322	5849	12·16	6·89
						6·54 Average

Activation parameters: $\Delta E^‡$ 17·5 ± 0·5 kcal mol^{-1}; A 8·8 × 10^5 l mol^{-1}; $\Delta H^‡$ 16·9 kcal mol^{-1}; $\Delta S^‡$ −35·8 cal mol^{-1} K^{-1}.

The alkaline decomposition of ethylthiourea gives small amounts of ethylammonium thiocyanate, which owing to the high concentration of sodium hydroxide (pH 12—13) in the starting solution and to the high volatility of ethylamine, b.p. 17°, was not recognized as such on the radiochromatograms but as sodium thiocyanate.

The pH measurements indicate (Table) that OH^- is consumed during desulphuration, as with thiourea,[3] according to equation (1) and as anticipated for a second-order reaction. The variation of pH is almost linear with time.

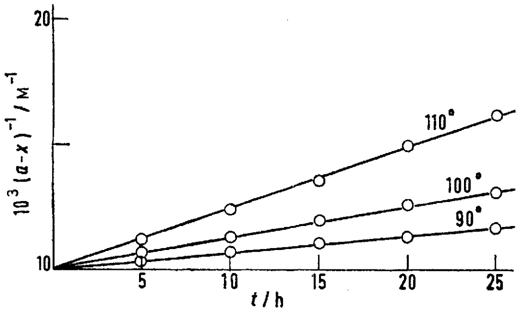

FIGURE 1 Plots of $10^3(a - x)^{-1}$ against t for solutions of ethylthiourea (0·1M) and NaOH (0·1M) at 90, 100, and 110° in Teflon containers

The desulphuration may be considered as an E_2 elimination (2) proceeding through nucleophilic attack of OH^- on the carbon atom of ethylthiourea, formation of an activated complex, and formation of ethylcyanamide[1,3] or as an S_N2 substitution (3) with formation of ethylisourea and then ethylurea, which, however, could also be formed through hydrolysis of ethylcyanamide formed by reaction (2).[6] Furthermore, ethylurea decomposes on heating in alkaline medium at pH > 12 into ammonia, ethylamine, and carbonic acid.

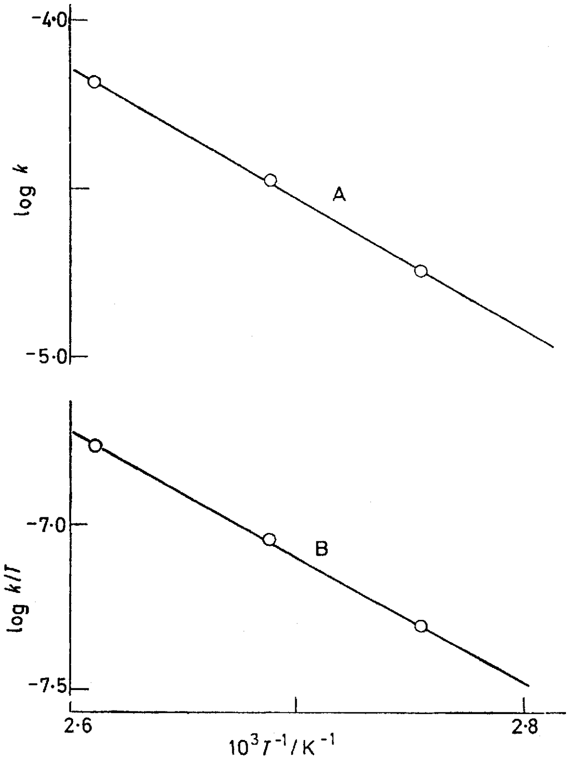

FIGURE 2 A, Arrhenius plot of log k and B, Eyring plot of log k/T against T^{-1}

The activation energy has the same value (*ca.* 18 kcal mol^{-1}) for both thiourea[3] and ethylthiourea desulphuration. This indicates that the inductive effect of the

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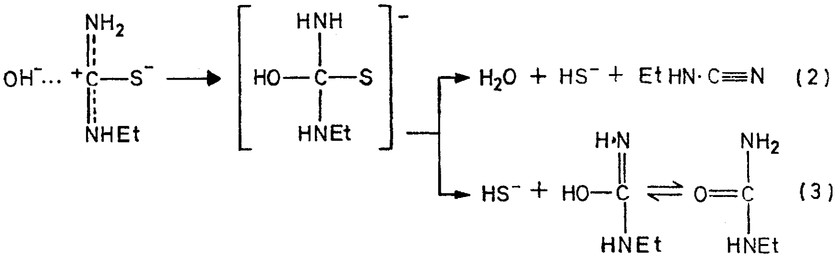
[6] R. H. Sahasrabudhey and R. Singh, *J. Indian Chem. Soc.*, 1954, **31**, 628.

ethyl group has practically no influence on the activation energy. On the contrary the rate constants are three times greater for thiourea [3] than for ethylthiourea.



$$OH^{-}\cdots{}^{+}C(NH_2)(NHEt)-S^{-} \longrightarrow [HO-C(HNH)(HNEt)-S]^{-} \longrightarrow H_2O + HS^{-} + EtHN{\cdot}C{\equiv}N \quad (2)$$

$$[HO-C(HNH)(HNEt)-S]^{-} \longrightarrow HS^{-} + HO-C(=NH)(HNEt) \rightleftharpoons O=C(NH_2)(HNEt) \quad (3)$$

This may be explained by the proposed reaction mechanism. Since amino-groups are necessary for the formation of H_2O and SH^- the two amino-groups of thiourea offer greater probability for the reaction than the single amino-group of ethylthiourea. Also steric hindrance by the ethyl group may influence the mechanism.

This work was supported by financial aid from the Consiglio Nazionale delle Ricerche, Italy.

[4/856 *Received, 29th April,* 1974]