Related Thermal Data

The heat of formation of SiO_2(cryst.) has been measured by Roth and Müller(6) who gave −204,000 cal ±2100 cal. as $\Delta H_{298.1}$ for the reaction Si(cryst.) + $O_2 \longrightarrow SiO_2$(cryst.). Using their value, the entropy of Si obtained from measurements from this Laboratory,(7) the entropy of oxygen from spectrographic data,(8) and the entropy of quartz, the free energy of formation is calculated to be −192,000 cal.

Summary

The heat capacities of quartz, cristobalite and tridymite from about 50 to 300°K. have been determined and their corresponding entropies calculated as 10.06, 10.34 and 10.50, respectively.

(6) Roth and Müller, *Z. physik. Chem.*, **A144**, 256 (1929).

(7) Anderson, THIS JOURNAL, **52**, 2301 (1930).

(8) Giauque and Johnston, *ibid.*, **51**, 2300 (1929).

BERKELEY, CALIF.

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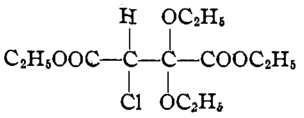
[CONTRIBUTION FROM THE CHEMICAL LABORATORIES OF BRYN MAWR COLLEGE AND THE UNIVERSITY OF ILLINOIS]

Products of the Reaction of Ethyl Dichloroacetate with Alcoholic Sodium Ethoxide

BY ARTHUR C. COPE

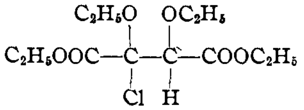
The reaction of ethyl dichloroacetate with alcoholic sodium ethoxide, which might be expected to be a practical method for the synthesis of ethyl diethoxy acetate, actually gives poor yields of the expected ester plus larger quantities of a higher boiling ester. Wohl and Lange(1) originally made this observation, and expressed the opinion that the high boiling material was formed by an acetoacetic ester condensation of the ethyl diethoxyacetate first produced, giving the keto ester $(C_2H_5O)_2CHCOC(OC_2H_5)_2COOC_2H_5$ (I). Their analysis, however, approached the formula $C_{12}H_{21}O_6Cl$, indicating that one of the ethoxyl groups was largely replaced by chlorine. Since recent work(2) has shown that monocarboxylic esters with only one alpha hydrogen atom do not undergo the acetoacetic ester condensation, structure I cannot be correct. Evidence which establishes the correct structure of the high boiling condensation product is presented in this paper.

The high boiling product decomposes slightly on distillation in vacuum. Zeisel determinations made on samples from successive distillations showed that each fractionation diminished the ethoxyl content. Material distilled rapidly at low pressures (0.1 to 2 mm.) gave analyses corresponding to the presence of four ethoxyl groups and the formula $C_{12}H_{21}O_6Cl$. The nature of the decomposition occurring during distillation was determined by heating samples at atmospheric pressure and identifying the products. The decomposition proceeded readily at 170 to 220° with the evolution of carbon monoxide, ethylene and a small amount of carbon dioxide. A low boiling distillate which was largely ethyl alcohol plus smaller quantities of ethyl formate and ethyl carbonate collected, and a high boiling liquid residue remained. Fractionation separated this residue into two portions. The lower boiling fraction was identified as ethyl chloromalonate by saponification to the acid and decarboxylation to chloroacetic acid. The higher boiling fraction was proved to be ethyl α-chloro-β-ethoxymaleate, $C_2H_5OOCCCl{=}C(OC_2H_5)COOC_2H_5$ (II), by saponification to the acid, which on heating gave α-chloro-β-ethoxymaleic anhydride. The isolation of this substituted maleic ester in 58% yield indicates the nature of the carbon chain in the original ester, which must therefore be a chlorodiethoxysuccinic ester, III or IV. Structure IV is improbable, since α-chloro ethers are usually too reactive to permit their isolation from alcoholic solution. III would be expected to lose alcohol on heating giving II; simultaneous loss of ethylene and carbon monoxide would explain the formation of the ethyl chloromalonate. Conclusive evidence that III is the correct structure for the high boiling condensation product was ob-



$$C_2H_5OOC-\underset{Cl}{\overset{H}{C}}-\underset{OC_2H_5}{\overset{OC_2H_5}{C}}-COOC_2H_5$$

III



$$C_2H_5OOC-\underset{Cl}{\overset{C_2H_5O}{C}}-\underset{H}{\overset{OC_2H_5}{C}}-COOC_2H_5$$

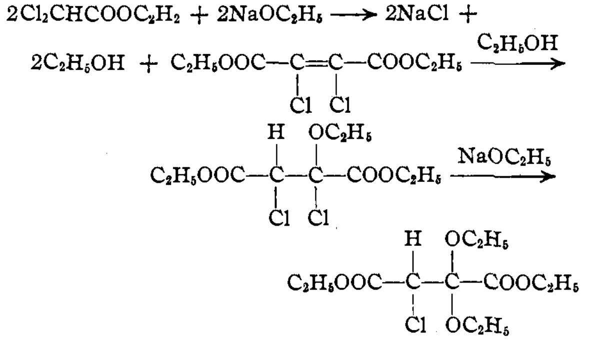
IV

(1) Wohl and Lange, *Ber.*, **41**, 3612 (1908).

(2) McElvain, THIS JOURNAL, **51**, 3124 (1929).

tained by its acid hydrolysis under mild conditions to ethyl oxalochloroacetate, $C_2H_5OOCCHClCOCOOC_2H_5$. This product could be formed only from III and not from IV.

It was proved by experiment that III is not formed from ethyl chloroethoxyacetate, $C_2H_5OCHClCOOC_2H_5$, and alcoholic sodium ethoxide, or from the reaction of ethyl dichloroacetate with ethyl diethoxyacetate and sodium ethoxide. Consequently the precursor of III must be the ethyl dichloroacetate alone. One sequence of reactions which could explain the formation of III is the following



$$2Cl_2CHCOOC_2H_2 + 2NaOC_2H_5 \longrightarrow 2NaCl +$$

$$2C_2H_5OH + C_2H_5OOC{-}\underset{Cl}{\underset{|}{C}}{=}\underset{Cl}{\underset{|}{C}}{-}COOC_2H_5 \xrightarrow{C_2H_5OH}$$

$$C_2H_5OOC{-}\overset{H}{\overset{|}{\underset{Cl}{\underset{|}{C}}}}{-}\overset{OC_2H_5}{\overset{|}{\underset{Cl}{\underset{|}{C}}}}{-}COOC_2H_5 \xrightarrow{NaOC_2H_5}$$

$$C_2H_5OOC{-}\overset{H}{\overset{|}{\underset{Cl}{\underset{|}{C}}}}{-}\overset{OC_2H_5}{\overset{|}{\underset{OC_2H_5}{\underset{|}{C}}}}{-}COOC_2H_5$$

Experimental Part

Reaction of Ethyl Dichloroacetate with Alcoholic Sodium Ethoxide.—This reaction was carried out by adding 1 mole of ethyl dichloroacetate[3] dropwise during an hour to a refluxing solution of 1.5 moles of sodium in 800 cc. of absolute alcohol. The solution was refluxed for one hour and then as much alcohol as possible distilled from a steam-bath (one to two hours). The residue was cooled in ice and ether added, followed by ice water. The ethereal layer was separated and the aqueous layer extracted twice with ether. The combined ether layers were washed once with ice water, dried over sodium sulfate and the ether distilled. The residue was distilled from a modified Claisen flask in vacuum. The fractions obtained were: (1) 62 g. b. p. 65° (19 mm.) to 122° (2 mm.); (2) 62 g. (42%) of III, b. p. 122–125° (2 mm.). Refractionation of (1) through a Widmer column gave 8 g. of recovered ethyl dichloroacetate and 43 g. (22%) of ethyl diethoxyacetate, b. p. 84–85° (14 mm.). Earlier preparations in which 2 moles of sodium ethoxide were employed gave the same yield of ethyl diethoxyacetate but only 18% of III. III had the following properties: $n^{25}{}_D$ 1.4355; $d^{25}{}_{25}$ 1.1167; M_D calcd. 69.39; obsd. 69.45.

Anal. Calcd. for $C_{12}H_{21}O_6Cl$: C, 48.55; H, 7.13; OC_2H_5, 60.73. Found: C, 48.54; H, 7.38; OC_2H_5, 60.20.

The purest samples of III were obtained by distilling at pressures of less than 1 mm., and temperatures of 100 to 110°.

Thermal Decomposition of III.—Fifty-gram samples were placed in a Claisen flask attached to a receiver and a gasometer. On heating in a metal bath ebullition started at 170° and was very vigorous at 220°. The residual liquid was heated for fifteen minutes at 250°. The gas evolved was analyzed in several cases; it contained 36 to 54% carbon monoxide, 34 to 54% ethylene and 11 to 13% carbon dioxide. Assuming that 2 moles of gas were formed from each mole of III which decomposed to give gaseous products, the yield of gas was 14 to 20%. The low boiling liquid which condensed in the receiver during the heating weighed 8 g. On distillation it could be separated into three fractions. The lowest boiling fraction (55–60°, 1.8 g.) was identified as ethyl formate by saponification at room temperature with 0.1 *N* sodium hydroxide to sodium formate, which was converted to *p*-phenylphenacyl formate, m. p. 72–74°. The intermediate fraction (76–78°, 4 g.) was identified as ethyl alcohol by preparation of the α-naphthyl urethan, m. p. 80–81°. The high boiling fraction (130–140°, 1.8 g.) was identified as ethyl carbonate by saponification to ethyl alcohol and sodium carbonate. The residue from the thermal decomposition (40 g.) was fractionated through a Widmer column. Two fractions were obtained; the lower boiling (7.5 g., b. p. 114–117° (17 mm.)) was identified as ethyl chloromalonate (23% yield) by saponification with alcoholic potassium hydroxide at room temperature to potassium chloromalonate.[4] The salt was acidified with dilute hydrochloric acid and the acid extracted with ether in a continuous extractor. After evaporation of the ether and extraction with hot chloroform the acid had m. p. 135° dec., and on heating to 160° for several minutes lost carbon dioxide, leaving a residue of chloroacetic acid which solidified on cooling, m. p. and mixed m. p. 62–63°. The higher boiling fraction (II) weighed 25 g. (58% yield); b. p. 150–152° (17 mm.). While the ester gave satisfactory carbon and hydrogen analyses, Zeisel determinations indicated that it was slightly impure.

Anal. Calcd. for $C_{10}H_{15}O_5Cl$: C, 47.88; H, 6.03; OC_2H_5, 53.92. Found: C, 48.04; H, 6.27; OC_2H_5, 51.30.

The ester was saponified by adding 10 g. to a solution of 5.6 g. of potassium hydroxide in 60 cc. of alcohol at room temperature. The solution became warm, and the potassium salt started to precipitate at once. After standing overnight the salt was filtered, washed with small volumes of alcohol and ether and dried; yield 7.8 g. (86%). A solution of the salt in 15 cc. of water was acidified with dilute sulfuric acid and extracted with ether in a small continuous extractor overnight. Evaporation of the ether left 4.7 g. of a partially crystalline acid, which on crystallization from 5 cc. of water gave 4.5 g. (74% from the salt) of α-chloro-β-ethoxymaleic acid monohydrate, m. p. 77–77.5°.

Anal. Calcd. for $C_6H_7O_5Cl \cdot H_2O$: C, 33.87; H, 4.26; OC_2H_5, 21.18. Found: C, 34.11; H, 4.45; OC_2H_5, 20.92.

The hydrated acid loses water very slowly on standing in air. On drying for four hours in vacuum at 35° it loses one molecule of water (calcd. H_2O 8.47%, found 8.51%) and gives the anhydrous acid, m. p. 88–88.5°.

Anal. Calcd. for $C_6H_7O_5Cl$: C, 37.01; H, 3.63; OC_2H_5, 23.15. Found: C, 36.98; H, 3.93; OC_2H_5, 23.34.

α-Chloro-β-ethoxymaleic acid, like other disubstituted maleic acids, loses water very readily, giving the corre-

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(3) Prepared from dichloroacetic acid which was prepared from chloral hydrate by the method of Delépine [*Bull. soc. chim.*, [4] **45**, 827 (1929)].

(4) Conrad and Guthzeit, *Ber.*, **15**, 605 (1882).

sponding anhydride. In preparing the anhydride, 0.50 g. of the hydrated acid was heated at 125° for fifteen minutes. The residue crystallized at once on cooling in ice and was purified by subliming at 100° and 1 mm. onto an ice-cooled receiver seeded with a crystal of the solid. The anhydride collected as a hard white crystalline mass; yield 0.40 g., m. p. 37–37.5°.

Anal. Calcd. for $C_6H_5O_4Cl$: C, 40.79; H, 2.85; OC_2H_5, 25.52. Found: C, 40.70; H, 3.08; OC_2H_5, 25.23.

Hydrolysis of III.—In one preparation of III as described above, only 300 cc. of alcohol was distilled from the reaction mixture, and in the ether extract there was consequently a considerable quantity of alcohol and water. The alcohol and water were removed as a fore-run in vacuum, but the high boiling ester obtained in this preparation (40 g.) was not III but was ethyl oxalochloroacetate, produced from III by hydrolysis of the acetal linkage. This strongly acidic enolic ester was completely soluble in sodium bicarbonate solution, from which it was reprecipitated by acids, and had b. p. 127–128° (9 mm.).

Anal. Calcd. for $C_8H_{11}O_5Cl$: OC_2H_5, 40.47. Found: OC_2H_5, 40.62.

The ester was identified completely by comparison with an authentic specimen prepared as by Wislicenus,[5] except that 200 cc. of ether was used as a solvent instead of 1 mole; yield 72%, b. p. 127–128° (9 mm.).[6] The known and unknown esters yielded identical condensation products with *m*-cresol, ethyl 3-chloro-7-methylcoumarin 4-carboxylate,[7] m. p. and mixed m. p. 150–151°. The samples also gave identical copper salts with aqueous copper acetate,[5] m. p. and mixed m. p. 178–179°. III could also be hydrolyzed to ethyl oxalochloroacetate in a more orthodox manner; 14.83 g. (0.05 mole) was dissolved in 50 cc. of alcohol and 1 cc. of concd. hydrochloric acid and 42 cc. of water were added. After standing for twelve hours 30 cc. more of water was added and the solution refluxed for ten minutes, cooled, added to 100 cc. of ice water and the ester extracted five times with ether. The ether was distilled and the residue dissolved in sodium bicarbonate solution. The solution was extracted with ether to remove any neutral material, then acidified with dilute sulfuric acid and again extracted five times with ether. After drying over sodium sulfate the product was distilled; yield of ethyl oxalochloroacetate 6.0 g., b. p. 127–128° (9 mm.). This sample gave a copper salt and condensation product with *m*-cresol identical with those described above.

Source of III.—In order to determine if ethyl chloroethoxyacetate, $C_2H_5OCHClCOOC_2H_5$, might be the precursor of III, 33.3 g. (0.2 mole) of this ester[8] was added to a solution of 2.3 g. of sodium in 60 cc. of absolute alcohol. The reaction mixture was treated in the manner described for the preparation of III. The only product obtained was 29 g. of ethyl diethoxyacetate, b. p. 85–87° (17 mm.). In a similar manner, 31.4 g. (0.2 mole) of ethyl dichloroacetate was added to a solution of 4.6 g. of sodium in 125 cc. of absolute alcohol, to which 35.2 g. (0.2 mole) of ethyl diethoxyacetate had been added. Only 6 g. of III was obtained on distillation of the product, the remainder being ethyl diethoxyacetate plus some recovered ethyl dichloroacetate. Since the yield of III from ethyl dichloroacetate is not increased by the presence of an excess of ethyl diethoxyacetate, it appears improbable that interaction of these two esters is responsible for the formation of III.

Summary

The reaction of ethyl dichloroacetate with alcoholic sodium ethoxide gives a small yield of ethyl diethoxyacetate plus larger quantities of ethyl oxalochloroacetate diethyl acetal. The latter compound loses alcohol readily on heating, giving ethyl α-chloro-β-ethoxymaleate, from which the corresponding substituted maleic acid and anhydride have been prepared.

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(5) Wislicenus, *Ber.*, **43**, 3529 (1910).

(6) The properties of this ester are being further investigated.

(7) Dey, *J. Chem. Soc.*, **107**, 1649 (1915).

(8) Mylo, *Ber.*, **44**, 3213 (1911).

BRYN MAWR, PENNA. RECEIVED FEBRUARY 1, 1936

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY]

Synthesis of Plumbagin

BY L. F. FIESER AND J. T. DUNN

Investigations of the active principle responsible for the various medicinal qualities attributed to roots of the plants *Plumbago europaea*, *P. zeylonica*, and *P. rosea* date from Dulong's[1] isolation of the substance plumbagin in a fairly pure condition in 1828. Except for occasional references to the preparation of the substance by steam distillation[2] or solvent extraction[3] of the plumbago root, or the Indian drug "Chita," the problem received little attention for a full century. Since 1928 the structure of plumbagin has been in part elucidated by the work of Indian and Spanish investigators, but the reports are in some cases contradictory and the evidence is still incomplete.

Roy and Dutt[4] recognized the quinone-like character of the yellow pigment, established the presence of an acidic hydroxyl group, and ob-

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(1) Dulong, *J. pharm. chim.*, **14**, 441 (1828).

(2) Flückiger, *N. Hantwörterb. Chem.*, **5**, 723 (1890).

(3) Wefers Bettink, *Rec. trav. chim.*, **8**, 319 (1889).

(4) Roy and Dutt, *J. Indian Chem. Soc.*, **5**, 419 (1928).