The Catalyzed Reaction of Acetylenedicarboxylic Acid and Thionyl Chloride

RICHARD N. McDONALD AND ROBERT A. KRUEGER[1a]

Department of Chemistry, Kansas State University, Manhattan, Kansas

Received March 18, 1963

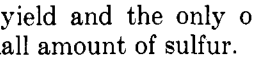
The reaction of acetylenedicarboxylic acid with thionyl chloride catalyzed by dimethylformamide, triethylamine, and pyridine yields a product of *cis* chlorination, dichloromaleic anhydride (III). With the latter two catalysts the yield of III is lower than with dimethylformamide, but a second product, bis[2-chloro-1,2-di(chloroformyl)vinyl] sulfide (VI), also is obtained. Possible mechanisms for the *cis* chlorination are discussed.

Diels and Thiele[1b] have reported the only synthesis of acetylenedicarbonyl chloride (I). The route employed by these authors was laborious and involved several steps from dimethyl acetylenedicarboxylate. The recorded melting point of 115° appears to be rather high for such a simple compound. In conjunction with another problem, we desired some of this diacid chloride, but were unsuccessful in several attempts to duplicate the preparation.

We then turned to other more direct methods for the synthesis of the diacid chloride I. It had been reported[1b] that treatment of acetylenedicarboxylic acid (II) with phosphorus pentachloride produced chlorofumaryl chloride rather than I. With the success of dimethylformamide-catalyzed thionyl chloride conversions of acids to acid chlorides[2] we decided to try this procedure on acetylenedicarboxylic acid (II).

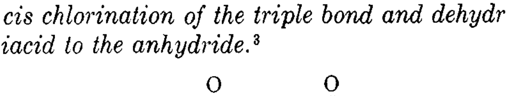
When a small amount of dimethylformamide was added to a suspension of the diacid II in thionyl chloride maintained at approximately 40° solution occurred in two hours. Dry nitrogen was bubbled through the mixture during this time in an effort to carry off the hydrogen chloride so that it would not add to the multiple bond of II, as was previously noted in the phosphorus pentachloride reaction. A solid product was obtained from this reaction which, after sublimation and recrystallization, had melting point of 122.5–123°.

The infrared spectrum of the product clearly showed the doublet carbonyl characteristic of anhydrides. Identification of this material as dichloromaleic anhydride (III) was made by comparison of its infrared and melting point with an authentic sample of III. Mixture melting point also showed no depression. III was isolated in 63% yield and the only other identifiable product was a small amount of sulfur. This result was rather surprising since the over-all process appears to be a *cis chlorination of the triple bond and dehydration of the diacid to the anhydride.*[3]



$$Cl-\overset{O}{\overset{\|}{C}}-C\equiv C-\overset{O}{\overset{\|}{C}}-Cl$$

I



II III

The following results were obtained in attempts to learn something regarding the mechanism of this reaction: (1) without dimethylformamide present no anhydride III is formed with only tars resulting, (2) the yield of III is constant with purified thionyl chloride but lower and erratic (35–50%) with various commercial samples, (3) monochloromaleic anhydride is not an intermediate in the formation of III since it is not converted to III under the reaction conditions, (4) pyridine and triethylamine also serve as catalysts but the yields of III are lower than with dimethylformamide, and (5) tetramethylammonium chloride does not function as a catalyst.

The latter result was obtained in an effort to see whether the halogenation proceeds by nucleophilic attack by chloride ion.[4] This would be a reasonable pathway from the proposed structure (IV) of the product from reaction of thionyl chloride and dimethylformamide.[2]

$$(CH_3)_2NCHO + SOCl_2 \longrightarrow [(CH_3)_2\overset{+}{N}{=}CHCl \longleftrightarrow (CH_3)_2N{-}\overset{+}{C}HCl]Cl^- + SO_2$$

IV

To determine whether dimethylformamide dichloride (IV) was the *cis* chlorinating species, IV was preformed[2] and allowed to react with acetylenedicarboxylic acid in dimethylformamide solution. We also were interested in this reaction as a possible route to the diacid chloride I. Methanolysis of the mixture gave as the only identifiable product either dimethyl chlorofumarate or maleate. The former product is more reasonable by the ionic addition of hydrogen chloride, produced in reaction of the adduct IV with the carboxylic acid groups, to the triple bond. None of the *cis*-chlorination product III was found as a product of this reaction.

It, therefore, seems most likely that the catalysts (dimethylformamide, pyridine, and triethylamine) serve to complex with thionyl chloride and that this complex reacts to add to the triple bond, possibly as is illustrated in structure V. This mechanism also accounts for the formation of sulfur.[5] The intermediacy of sulfur monoxide recently has been proposed by other investigators[6] to explain certain results.

The triethylamine- and pyridine-catalyzed reactions were of further interest since both yielded a second re-

---

[1] (a) A portion of a dissertation to be presented by R. A. Krueger to the Graduate School of Kansas State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy; (b) O. Diels and W. E. Thiele, *Ber.*, **71B**, 1173 (1938).

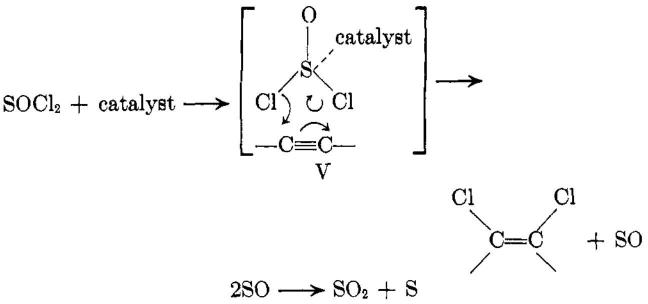
[2] H. H. Bosshard, R. Mory, M. Schmid, and H. Zollinger, *Helv. Chim. Acta*, **42**, 1653 (1959).

[3] Diels and Thiele[1b] reported a similar *cis* chlorination of a double bond when a disubstituted maleic anhydride (the anhydride from the anthraceneacetylenedicarboxylic acid adduct) was treated with phosphorus pentachloride.

[4] It is not known whether tetramethylammonium chloride is ionized in thionyl chloride or not. The amount of this salt used was readily soluble in the reaction mixture.

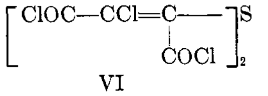
[5] When a small amount of dimethylformamide is added to thionyl chloride and the mixture held at 40° for four hours, no sulfur is observed on evaporation of the thionyl chloride.

[6] L. F. Fieser and Y. Okumura, *J. Org. Chem.*, **27**, 2247 (1962); H. H. Szmant and L. M. Alfonso, *J. Am. Chem. Soc.*, **79**, 205 (1957); and H. E. Simmons, D. C. Blomstrom, and R. D. Vest, *ibid.*, **84**, 4772 (1962).



action product. It was "fractionally sublimed" at 0.6–0.4 mm.[7] from the anhydride III. This second product was found to contain sulfur and chlorine by sodium fusion and ionic chloride ion when treated with alcoholic silver nitrate.

The infrared spectrum showed a closely spaced carbonyl doublet (5.46 and 5.49 μ) assigned to that of acid chloride groups and unsaturation at 6.2 μ. It exhibited a maximum in the ultraviolet spectrum at 309 mμ (ϵ 11,374) in cyclohexane and a molecular weight of 412. No proton magnetic resonance could be observed in carbon tetrachloride except for a small amount due to hydrogen attached to oxygen, presumably due to some hydrolysis of the acid chloride functions. This information appeared to be consistent with that of structure VI, bis[2-chloro-1,2-di(chloroformyl)vinyl] sulfide. The sulfoxide of VI[8] is ruled out by elemental analysis.

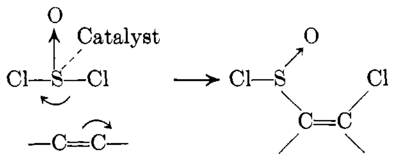


$$\left[\mathrm{ClOC{-}CCl{=}\underset{\substack{|\\ COCl}}{C}{-}{-}}\right]_2\mathrm{S}$$

VI

The presence of the four acid chloride groups of VI was established by converting it to the tetraamide with diethylamine. In this product the infrared bands at 8.46 and 9.59 μ were absent. The skeleton of VI was shown by Raney nickel desulfurization and hydrogenation to yield as the only product diethyl succinate.

Formation of VI can be accounted for by a somewhat different mode of addition of the thionyl chloride–catalyst complex, apparently involving a four-centered activated state.[10] Repetition of this process would give



rise to the sulfoxide of VI which could be reduced by elemental sulfur or sulfur monoxide formed in the process to produce dichloromaleic anhydride (III). However, we have not established the geometry of double bonds of VI as *cis*.

Experimental[11]

Reaction of Acetylenedicarboxylic Acid and Thionyl Chloride.—A suspension of 10.0 g. (0.088 mole) of acetylenedicarboxylic acid and 80 ml. of triply distilled thionyl chloride was heated at 40° with a stream of nitrogen bubbling through the mixture. Heating was continued for about 8 hr. until almost all of the solid had dissolved. The excess thionyl chloride was removed at reduced pressure from the black solution yielding a thick black gum. From this could be pumped off, into an ice trap 0.4 g. of a mixture of chloropropiolic acid chloride and chlorofumaryl chloride was identified by infrared analysis. No attempt was made to fractionate this mixture. A black resinous mass was left after pumping this mixture from the reaction product.

Similar results were obtained when the reaction was carried out in the presence of 0.5 g. of tetramethylammonium chloride.

Catalyzed Reaction of Acetylenedicarboxylic Acid with Thionyl Chloride. A. Dimethylformamide Catalyst.—A suspension of 10.0 g. (0.088 mole) of acetylenedicarboxylic acid, 80 ml. of triply distilled thionyl chloride, and 0.5 ml. of dimethylformamide was heated at 40° with a stream of nitrogen bubbling through the mixture. The temperature was maintained until all of the solid dissolved ($\sim$2 hr.) giving a light yellow-red solution. The excess thionyl chloride was removed under reduced pressure at room temperature and the residual dark solid dissolved in the minimum amount of methylene chloride and transferred to a sublimation apparatus. The solvent was boiled off in a stream of nitrogen and the dark semisolid sublimed at 0.4 mm. and 55°. The colorless sublimate[12] weighed 9.2 g. (63%) which after one recrystallization from cyclohexane had m.p. 122.5–123°. This was identified as dichloromaleic anhydride by comparison of the infrared spectrum and melting point with an authentic sample. A mixture melting point showed no depression.

B. Triethylamine Catalyst.—The reaction was carried out as in method A except that 0.5 ml. of dry triethylamine was used as catalyst. Work-up in the same manner yielded 7.2 g. of a dark, slightly wet sublimate. This was resublimed at 0.4 mm. and 60° to give 5.8 g. (40%) of colorless dichloromaleic anhydride, m.p. 122–122.5°.

The sublimation residue after removal of the anhydride was found to sublime at 0.4 mm. and 130° to give 0.5 g. of a colorless crystalline solid, m.p. 135–136.5°. The identity of this compound was shown to be that of VI in the pyridine-catalyzed reaction.

C. Pyridine Catalyst.—A mixture of 20.0 g. (0.18 mole) of acetylenedicarboxylic acid, 120 ml. of triply distilled thionyl chloride, and 1 ml. of dry pyridine with nitrogen bubbling through it was heated at 40° overnight. After removal of the excess thionyl chloride under reduced pressure at room temperature the solid was transferred to the sublimer in the same manner. Dichloromaleic anhydride (11.5 g., 39%) sublimed readily at 0.4 mm. and 50° leaving a considerable amount of dark semisolid.

This semisolid was extracted with hot cyclohexane and the solution, after decolorizing with Norit, was transferred to the sublimer. This was warmed on a steam bath and a stream of dry nitrogen was used to blow off the solvent. The tan solid was found to sublime at 0.4 mm. and 130° to yield 6.2 g. (17%) of a light yellow product, m.p. 138–139°. The analytical sample was resublimed under these conditions and recrystallized once from cyclohexane to give needles, m.p. 138–139°.

Anal. Calcd. for $C_8Cl_6O_4S$: C, 23.73; Cl, 52.55; S, 7.92; mol. wt., 405. Found: C, 24.02; H, 0.20; Cl, 53.21; S, 8.27; mol. wt., 412 (carbon tetrachloride).[13]

This material had a doublet carbonyl absorption in the infrared spectrum at 5.46 and 5.49 μ characteristic of acid chlorides, and unsaturation absorption at 6.2 μ. Its ultraviolet spectrum in cyclohexane showed a maximum at 309 mμ (ϵ 11,347) with a minimum at 255 mμ and end absorption below this value. This was identified as bis[2-chloro-1,2-di(chloroformyl)vinyl] sulfide (VI) by the following experiments.

Reaction of Bis[2-chloro-1,2-di(chloroformyl)vinyl] Sulfide (VI) with Diethylamine.—A small amount of VI in chloro-

---

[7] No separation was observed when the pressure was reduced to 0.03 mm., where both compounds readily sublimed at 50°.

[8] The reason for considering the sulfoxide of VI is the presence of two intense bands on the infrared at 8.46 and 9.59 μ which have been assigned to the sulfoxide group.[9]

[9] L. J. Bellamy, "The Infrared Spectra of Complex Molecules," 2nd Ed., John Wiley and Sons, Inc., New York, N. Y., 1958, pp. 357–360.

[10] This appears most reasonable since neither VI nor any other similar product is formed in the uncatalyzed reaction or in the presence of tetramethylammonium chloride.

[11] All melting points were determined on a Kofler hot stage. Infrared absorption spectra were determined using Perkin-Elmer Model 137 or 237 double beam recording spectrophotometers. Ultraviolet spectra were determined using a Cary Model 11.

[12] Essentially all of the semisolid sublimed under these conditions except for a small amount of sulfur.

[13] Molecular weights were determined using the Mechrolab osmometer Model 301A in the solvent given.

form was treated with an excess of diethylamine in the same solvent. After standing at room temperature for several hours water was added and the organic layer separated. This was washed with dilute hydrochloric acid followed by water and dried over sodium sulfate. Evaporation of the solvent left a liquid residue whose infrared spectrum showed a single carbonyl absorption at 6.0 μ. This liquid crystallized from a mixture of ethanol and water to give colorless crystals, m.p. 116–117.5°. A second recrystallization gave material melting at 116–117°.

Anal. Calcd. for $C_{24}H_{40}Cl_2N_4O_4S$: C, 52.26; H, 7.31; Cl, 12.86; N, 10.16; S, 5.81; mol. wt., 552. Found: C, 52.32; H, 7.37; Cl, 13.16; N, 10.39; S, 5.92; mol. wt., 556 (carbon tetrachloride).[13]

No absorption maximum was observed in the ultraviolet spectrum, only end absorption below 285 mμ.

Raney Nickel Desulfurization of Tetraethyl Ester of VI.—A mixture of 1.6 g. (0.004 mole) of IV in 15 ml. of ethanol was refluxed overnight. To the resulting solution, 25 g. of freshly prepared Raney Nickel catalyst[14] was added and refluxing was continued for an additional 48 hr. The mixture was then placed in a low pressure hydrogenation bomb at 50 p.s.i. for 16 hr. The catalyst was filtered off and washed twice with ethanol. The filtrates were combined and reduced to a volume of approximately 5 ml. by distillation of the excess solvent through a Vigreux column. The green solution remaining was placed on a column of neutral alumina and eluted with chloroform. The volume of the eluate was reduced to approximately 2 ml. on a hot water bath. The resulting light yellow solution was then further purified by vapor phase chromatography. The retention time of the product was in agreement with that of an authentic sample of diethyl succinate.

Agreement was also found in the infrared spectra of the hydrogenation product and diethyl succinate. A pure sample from the v.p.c. was used to obtain an n.m.r. spectrum which was in agreement with that previously published.[15] The yield based on the v.p.c. collected material was 44.4%.

Reaction of Acetylenedicarboxylic Acid with Dimethylformamide Dichloride.—Dimethylformamide dichloride was prepared from dimethylformamide and phosphorus pentachloride.[2] A solution of 5.6 g. (0.05 mole) of acetylenedicarboxylic acid in dimethylformamide was added dropwise to 25.6 g. (0.2 mole) of dimethylformamide dichloride in dimethylformamide maintained at 0° and vigorously stirred. The reaction mixture was stirred overnight and allowed to stand for 1 day. Methanol was then added and the mixture was diluted with water and extracted with ether. The ether extract was washed with 10% sodium bicarbonate (no gas evolved) and dried over sodium sulfate. After filtering the ether solvent was distilled and the residue remaining was purified by v.p.c.[16]

The major component, other than solvent, had a retention time of 10.17 min. The collected sample had n^{20}_{D} 1.4623 and was shown to contain chlorine by sodium fusion. The n.m.r. spectrum in deuteriochloroform exhibited three singlets at 6.11, 6.23, and 6.63 τ (with respect to tetramethylsilane internal standard) in a ratio of 3:3:1. It had λ_{max}^{EtOH} in the ultraviolet at 218 mμ (ϵ 4700) and in the infrared the following peaks were observed: 3.38 (m), 5.71 (s), 6.09 (s), 6.94 (s), 7.39 (s), 7.86 (s), 8.25 (s), 8.51 (s), 9.65 (s), 9.85 (s), 10.37 (w), 11.09 (m), 11.40 (m), 11.92 (w), 12.85 (w), 13.42 (m), and 13.91 (m) μ (neat).

Acknowledgment.—The authors wish to express their gratitude to the National Science Foundation (NSF-G17430 and NSF-G18627) for support of this research. The Varian A-60 proton magnetic spectrometer used in this investigation was purchased with matching funds which were greatly appreciated from the National Science Foundation.

---

[14] L. W. Covert and H. Adkins, *J. Am. Chem. Soc.*, **54**, 4416 (1932).

[15] N. S. Bhacca, L. F. Johnson, and J. N. Shoolery, "NMR Spectra Catalog," Varian Associates, Palo Alto, Calif., 1962, Spectra no. 215.

[16] Conditions: column, 6 ft. × 0.25 in. in diameter, silicone oil 220; sample size, 2 μl.; gas flow, 46 ml./min.; injection port, 327°; detector block, 350°; column temperature programmed from 100° to 225° at 11°/min.

Dehydrobromination of *cis*-2,6-Dibromo-4,4-dimethylcyclohexanone and of *cis*-2,6-Dibromo-4,4-diphenylcyclohexanone

FREDERICK G. BORDWELL AND KEITH M. WELLMAN[1]

Department of Chemistry, Northwestern University, Evanston, Illinois

Received February 11, 1963

2-Bromo-4,4-dimethylcyclohex-2-enone was observed to be the major product formed in the dehydrobromination of *cis*-2,6-dibromo-4,4-dimethylcyclohexanone by quinoline. This result and a comparable result observed for the dimethylformamide-calcium carbonate dehydrobromination of *cis*-2,6-dibromo-4,4-diphenylcyclohexanone are best accommodated mechanistically as 1,4-eliminations upon the corresponding enols.

Dehydrobromination of crude 2,6-dibromo-4,4-dimethylcyclohexanone (I) by heating with quinoline at 170° has been reported[2] to give 2-bromo-4,4-dimethylcyclohex-2-enone (II) as the major product, accompanied by smaller amounts of 4,4-dimethylcyclohexa-2,5-dienone (III). Transformations like that of I to II also have been observed in the steroid field.[3] It appeared to be of interest to investigate this unusual reaction to see whether additional information concerning its mechanism could be obtained.

Treatment of pure *cis*-2,6-dibromo-4,4-dimethylcyclohexanone with quinoline under the conditions described[2] gave a low yield of isolable product. This product was separated by fractional distillation and chromatography into a major component, m.p. 29°, and a minor liquid component. The latter proved to be the dienone III. This result differed from that reported previously[2] in that the major component of the mixture (presumed to be II) was reported to melt at 84–86°. Nevertheless, the compound melting at 29° was identified as II. The structure was established by preparing an authentic sample of II from 4,4-dimethylcyclohex-2-enone (IV) by addition of bromine followed by pyridine dehydrobromination. (See p. 2545, top of col. 1.)

On repetition of the experiment using *crude* 2,6-dibromo-4,4-dimethylcyclohexanone, a product melting at 85.5° was isolated, in agreement with the original report.[2] The ultraviolet spectrum reported for this compound (λ_{max} 245 mμ, shoulder at 270 mμ)[4] gave a

---

[1] Union Carbide Corporation Fellow, 1959–1960; Eastman Kodak Company Fellow, 1961–1962.

[2] M. Yanagita, A. Tahara, and E. Ohki, *J. Pharm. Soc.* (Japan), **71**, 1060 (1951).

[3] C. Djerassi and D. Marshall, *J. Am. Chem. Soc.*, **80**, 3986 (1958); C. Djerassi and C. R. Scholz, *ibid.*, **69**, 2404 (1947); C. Djerassi and G. Rosenkranz, *Experimentia*, **7**, 93 (1951); see also M. E. Kuehne, *J. Am. Chem. Soc.*, **83**, 1492 (1961); M. Yanagita, *et al.*, *J. Org. Chem.*, **22**, 291 (1957); **21**, 500 (1956); **18**, 792 (1953).

[4] M. Yanagita and S. Inayama, *ibid.*, **19**, 1724 (1954). The values cited are taken from curves B and D.