diluted with ether, washed with 10% sodium bicarbonate, and dried. Solvent was removed on a rotary evaporator under reduced pressure to give 2.3 g. of partially crystalline residue. Crystallization from toluene afforded 1.2 g. of product melting at 130–150°. Recrystallization from chloroform followed by recrystallization from ethanol gave 0.59 g. (23% yield) of VII as white plates, m.p. 170–172° (lit.,[2] m.p. 172–174°); λ_{max}^{KBr} 2.92, 5.90, 6.21, and 6.33 μ.

Anal. Calcd. for $C_{16}H_{18}O_3$: C, 74.4; H, 7.01; mol. wt., 258. Found: C, 73.9; H, 6.91; mol. wt. (mass spectroscopy), 258.

The Preparation of Carbodiimides, Isocyanates, and Isothiocyanates by Metal Ion-assisted Elimination of Mercaptan[1,2]

ARTHUR F. FERRIS AND BEVERLY A. SCHUTZ

Midwest Research Institute, Kansas City 10, Missouri

Received July 26, 1962

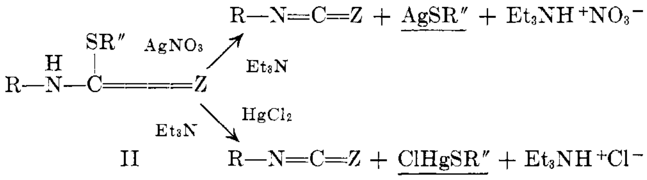
Solutions of reactive intermediates of structure I (carbodiimides, isocyanates, and isothiocyanates) which may be used for subsequent reaction without further treatment may be prepared conveniently by treating compounds of structure II with solutions of silver nitrate or mercuric chloride. An alkyl mercaptan is eliminated in the reaction as an insoluble metal mercaptide. In typical experiments, products of condensation of the intermediates with amines or alcohols were obtained in 50–100% yield.

Compounds of the general structure I, namely the carbodiimides (Z = NR′), the isocyanates (Z = O),

$$R—N{=}C{=}Z \qquad Z = NR', O, \text{ or } S$$

and the isothiocyanates (Z = S) are widely useful as intermediates,[3] but frequently high reactivity, instability, and/or lachrymatory properties make them difficult to handle in the isolated state.

In the present study it has been found that solutions of intermediates of type I may be prepared by heavy metal ion-assisted elimination of mercaptan from molecules of type II. The elimination is effected by treating a solution of a compound of type II with a solution of silver nitrate or mercuric chloride in the presence of an acid acceptor. The heavy metal mercaptide is formed rapidly under mild conditions and precipitates, leaving a solution of the reactive intermediate which may be used directly for subsequent reaction. The elimination reaction is not without precedent, since strong heating is known to eliminate mercaptan from N,S-disubstituted dithiocarbamates,[4] and elimination of heavy metal sulfides from 1,3-disubstituted thioureas[3b] and dithiocarbamate salts[5] is well known. For small scale synthetic work, however, it is apparent that the new technique offers considerable convenience, since it obviates the necessity for isolating and purifying the reactive intermediate and provides optimum conditions for rapid reaction and high yields. In the discussion which follows, the elimination reaction will be considered primarily in terms of its utility as a synthetic method.



Starting materials for the synthesis of the carbodiimides are the 1,2,3-trisubstituted thiopseudoureas[6]; for the isocyanates, the N,S-disubstituted thiolcarbamates[7]; and for the isothiocyanates, the N,S-disubstituted dithiocarbamates.[8] All are prepared by well known methods. The only metal salts which have been found useful for mercaptan elimination are silver nitrate and mercuric chloride. Both are soluble in a fair number of organic solvents, react rapidly with compounds of type II, and given mercaptides insoluble in most organic solvents as long as the alkyl group which is eliminated (R″ in II) is small. Zinc chloride is also soluble in many organic solvents, but usually does not assist the elimination reaction. Acetonitrile and dimethylformamide are the best solvents for the silver nitrate reaction, and acetone, methanol, ethanol, and dimethylformamide for the mercuric chloride reaction. Though dimethyl sulfoxide is a good solvent for both metal salts, large amounts of tarry by-products are formed when it is used. As a matter of convenience, triethylamine has been used most commonly as the acid acceptor.

The elimination reaction is carried out by adding a solution of the metal salt to a solution of the substrate (II) and the acid acceptor at room temperature or below. The reaction is exothermic and sometimes requires cooling. The silver mercaptides precipitate instantly, frequently in very finely divided form. A small amount of diatomaceous earth added to the reaction mixture *before* precipitation of the silver mercaptide gives a more easily filtered solid. Formation of the mercury mercaptides is usually complete in half an hour, and they precipitate in granular form. The alkylmercaptomercuric chloride (RSHgCl) is formed, not the dimercaptide (RSHgSR).[9] When the elimination reaction is complete, carbodiimide and isothiocyanate solutions may be filtered and used directly for

---

[1] This work was supported by the U. S. Army Medical Research and Development Command, Department of the Army, under Contract no. DA-49-193-MD-2174.

[2] Presented in part at the Thirteenth Annual Kansas City Chemistry Conference, November 17, 1961.

[3] See, for example: (a) I. D. Morton and E. Hoggarth, "Chemistry of Carbon Compounds," Vol. IB, E. H. Rodd, ed., Elsevier Publishing Co., Amsterdam, 1952, pp. 939 and 945; (b) H. G. Khorana, *Chem. Rev.*, **53**, 145 (1953); (c) J. R. Schaeffer, *Org. Chem. Bull.*, **33**, No. 2 (1961).

[4] E. E. Reid, "Organic Chemistry of Bivalent Sulfur," Vol. IV, Chemical Publishing Co., Inc., New York, N. Y., 1962, p. 239.

[5] Ref. 4, p. 215.

[6] Ref. 4, Vol. I, p. 32.

[7] W. H. Schuller and C. Niemann, *J. Am. Chem. Soc.*, **75**, 3425 (1953).

[8] Ref. 4, Vol. I, p. 923.

[9] The nature of the mercury mercaptide was established by treating 1,3 diphenyl-2-*n*-propyl-2-thiopseudourea with mercuric chloride in acetone. *n*-Propylmercaptomercuric chloride, a compound of known[10] melting point, was obtained in 84% yield.

[10] Ref. 4, Vol. I, p. 145.

whatever subsequent reaction is desired. The more water sensitive isocyanate solutions are best treated with the condensing reagent before filtration to avoid excessive exposure to water vapor of the air.

As nearly as can be determined, yields of the reactive intermediates (I) obtained by mercaptan elimination are essentially quantitative. The yields of final products depend on the occurrence of side reactions in the second step and on the usual isolation problems, and in typical experiments have ranged from almost quantitative down to about 50%. The reactive intermediates themselves have been isolated in a few cases, but because of isolation difficulties, the yields of the intermediates were usually lower than those of secondary products derived from reaction of the same intermediates in solution.

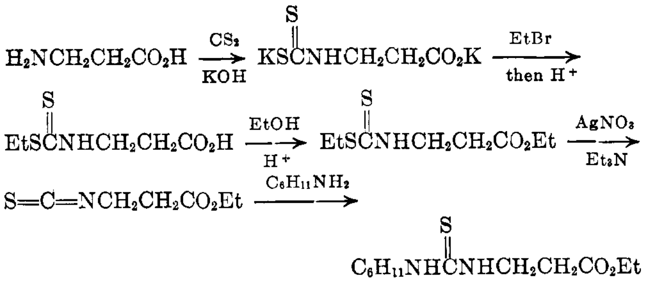
In representative experiments in the carbodiimide series (I. Z = NR′), various 2-alkyl-1,3-diphenylthiopseudoureas were treated with solutions of silver nitrate or mercuric chloride, and the resulting diphenylcarbodiimide solutions were converted to 1,3-diphenylurea (89%) by mineral acid, to 1,3-diphenylguanidine (62%) by ammonium nitrate, and to 1,2,3-triphenylguanidine (60%) by aniline hydrochloride. A solution of diisopropylcarbodiimide prepared by the action of silver nitrate in acetonitrile on 2-ethyl-1,3-diisopropylthiopseudourea gave a 60% yield of 1,3-diisopropylurea when treated with acetic acid. Isolation of diisopropylcarbodiimide from a similar preparation gave a 43% yield of distilled material.

One of the most valuable applications of carbodiimides in organic synthesis is their use as water abstractors in ester and amide preparations.[3b,c] In such reactions the carbodiimide is converted to the corresponding urea, and isolation of the ester or amide depends on a considerable solubility difference between the desired product and the urea. In situations where it is desirable to have the by-product urea *more* soluble than the ester or amide, diethylcarbodiimide is a particularly convenient condensing agent, since 1,3-diethylurea is soluble in water and many other solvents. Although diethylcarbodiimide is reported[3b] to be too unstable to store, solutions of this carbodiimide were prepared readily from 2-methyl-1,3-diethylthiopseudourea by mercaptan elimination. An acetonitrile solution gave a 64% yield of phenylacetanilide at room temperature from equimolar amounts of phenylacetic acid and aniline, and a methanol solution reacted with *p*-nitrobenzoic acid to give a 53% yield of methyl *p*-nitrobenzoate.

In view of the water sensitivity of the isocyanates (I. Z = O), no attempt was made to isolate the representatives of this class prepared by mercaptan elimination. The isocyanates were treated as rapidly as possible with amines or alcohols, and the resulting urea or urethanes were the first products isolated. In typical experiments, S-methyl N-phenylthiolcarbamate (prepared in 96% yield from aniline and methyl chlorothiolformate) was treated with silver nitrate in acetonitrile to give solutions of phenyl isocyanate. These reacted with *n*-butylamine to give 1-*n*-butyl-3-phenylurea in 82% yield (*n*-butylamine as acid acceptor), with diethylamine to give 1,1-diethyl-3-phenylurea in 82% yield (triethylamine as acid acceptor), and with dimethylamine (generated in solution from dimethylamine hydrochloride and triethylamine) to give 1,1-dimethyl-3-phenylurea in 71% yield. Treatment of S-methyl N-phenylthiolcarbamate with mercuric chloride in dry acetone gave a solution of phenyl isocyanate which reacted with cyclohexylamine to give 1-cyclohexyl-3-phenylurea in quantitative yield. *n*-Butylamine with methyl chlorothiolformate gave a crude thiolcarbamate, which, on treatment with silver nitrate in acetonitrile and then with aniline, gave 1-*n*-butyl-3-phenylurea in 78% yield. S-Methyl N-(4-ethoxycarbonyl)phenylthiolcarbamate reacted with silver nitrate in the presence of allylamine to give 1-allyl-3-(4-ethoxycarbonyl)phenylurea in 93% yield and with mercuric chloride in ethanol to give O-ethyl N-(4-ethoxycarbonylphenyl)carbamate in 94% yield.

In the isothiocyanate series (I. Z = S) the only example of a compound of type I which did not react satisfactorily in solution was encountered. Ethyl S-ethyldithiocarbamoylacetate[11] was converted readily by the action of silver nitrate in acetonitrile to ethyl isothiocyanatoacetate, which could be isolated in 60% distilled yield. However, when solutions of ethyl isothiocyanatoacetate in acetonitrile were treated with various amines in an effort to get 5-substituted 4-thiohydantoic esters, intensely colored tarry masses were obtained from which no well defined products could be isolated. An ethanol solution of ethyl isothiocyanatoacetate reacted with aniline to give a red tar from which it was possible to isolate 3-phenyl-2-thiohydantoin in 37% yield. It appears that cyclization is an almost inevitable concomitant of reactions of ethyl isothiocyanatoacetate with amines in polar solvents such as those necessary for the elimination reaction.

When cyclization was less favored, no difficulty was encountered in isolating the expected products. Crude ethyl 3-(ethyldithiocarbamoyl)propionate (from β-alanine) reacted with silver nitrate to give ethyl 3-isothiocyanatopropionate. This was isolated in 53% distilled yield and, in contrast to the isothiocyanatoacetate, gave a 64% yield of 1-cyclohexyl-3-(2-ethoxycarbonylethyl)-2-thiourea when the unpurified solution was treated with cyclohexylamine.



$$H_2NCH_2CH_2CO_2H \xrightarrow[KOH]{CS_2} KS\overset{\overset{S}{\|}}{C}NHCH_2CH_2CO_2K \xrightarrow[\text{then } H^+]{EtBr}$$

$$EtS\overset{\overset{S}{\|}}{C}NHCH_2CH_2CO_2H \xrightarrow[H^+]{EtOH} EtS\overset{\overset{S}{\|}}{C}NHCH_2CH_2CO_2Et \xrightarrow[Et_3N]{AgNO_3}$$

$$S{=}C{=}NCH_2CH_2CO_2Et \xrightarrow{C_6H_{11}NH_2} C_6H_{11}NH\overset{\overset{S}{\|}}{C}NHCH_2CH_2CO_2Et$$

Isothiocyanate formation also took place readily in simple systems. S-Ethyl N-methyldithiocarbamate reacted in acetonitrile with silver nitrate to give a solution of methyl isothiocyanate, which in turn gave a 65% yield of 1-*t*-butyl-3-methyl-2-thiourea[12] with *t*-butylamine.

---

(11) H. Korner, *Ber.*, **41**, 1901 (1908).

(12) E. Schmidt, W. Striewsky, and F. Hitzler, *Ann.*, **560**, 222 (1948).

Experimental[13,14]

Typical experiments covering all the variations in technique employed are presented below. All products mentioned in the Discussion and not described below are known compounds, identified by agreement between their physical properties and those reported in the literature and by infrared spectra.

1,3-Diphenylguanidine.—To a solution of 6.1 g. (0.025 mole) of 2-methyl-1,3-diphenylthiopseudourea and 2.5 g. (0.025 mole) of triethylamine in 20 ml. of dimethylformamide containing 2.0 g. of suspended filter-aid was added a solution of 4.2 g. (0.025 mole) of silver nitrate in 15 ml. of dimethylformamide. The yellow precipitate was removed by suction filtration and washed with 25 ml. of dimethylformamide and then with acetone. Then 4.0 g. (0.05 mole) of ammonium nitrate was dissolved in the dimethylformamide filtrate, and the solution was held at 50–55° for 40 hr. The reaction mixture was poured into 200 ml. of water, the small amount of solid which separated was removed by filtration, and the filtrate was made strongly basic with 10% sodium hydroxide solution. The solid which came out was recovered by suction filtration and dried. The silver methyl mercaptide and filter-aid amounted to 6.1 g. (theory 5.9 g.). The 1,2-diphenylguanidine amounted to 3.3 g. (62%), m.p. 140–146°. Recrystallization from ethanol gave pure 1,2-diphenylguanidine, m.p. 148–150° (lit.,[15] m.p. 148–148.5°).

1,2-3-Triphenylguanidine.—To a solution of 6.1 g. (0.025 mole) of 2-methyl-1,3-diphenylthiopseudourea and 2.3 g. (0.025 mole) of aniline in 15 ml. of dimethylformamide was added a solution of 6.8 g. (0.025 mole) of mercuric chloride in 20 ml. of dimethylformamide. A white solid precipitated. The mixture was held at 50–55° for 40 hr., then the solid was removed by suction filtration and washed with 20 ml. of dimethylformamide. The filtrate was poured into a solution of 1.0 g. (0.025 mole) of sodium hydroxide in 200 ml. of water, and a creamy white solid separated. Addition of an aqueous solution of sodium sulfide caused a black solid to precipitate. The black and white solids were recovered by suction filtration, and the wet cake was heated with 75 ml. of 95% ethanol. The white solid went into solution; the black remained undissolved and was removed by filtration. To the filtrate was added 10 ml. of water and on cooling a white solid crystallized. After recovery by suction filtration and drying, it amounted to 3.5 g., m.p. 138–141°. Partial evaporation of the filtrate and crystallization gave another 0.8 g. of solid, m.p. 132–138°. Total recovery of 1,2,3-triphenylguanidine was 4.3 g. (60%). Two recrystallizations from ethanol gave pure material, m.p. 144–146° (lit.,[16] m.p. 144–145°).

Phenylacetanilide from Phenylacetic Acid and Aniline.—To a solution of 26.4 g. (0.20 mole) of 1,3-diethyl-2-thiourea in 100 ml. of acetone was added 35.5 g. (0.25 mole) of methyl iodide. The mixture warmed spontaneously to reflux. When the temperature had dropped back to 30° the acetone was evaporated under reduced pressure, and solid crystallized. The solid was slurried in 100 ml. of anhydrous ether, recovered by suction filtration, and dried *in vacuo*. A total of 54.5 g. (99%) of crude 1,3-diethyl-2-methylthiopseudourea iodide was recovered.

To a cold solution of 13.7 g. (0.05 mole) of the iodide in 15 ml. of water was added 20 ml. of 10% sodium hydroxide solution. The homogeneous solution was extracted with two 50-ml. portions of ether, and the ether solution was dried over anhydrous magnesium sulfate for 2 hr. Evaporation of the ether left 7.0 g. (96%) of crude liquid 1,3-diethyl-2-methylthiopseudourea. This was taken up in 50 ml. of acetonitrile, and 5.1 g. (0.05 mole) of triethylamine and 2.0 g. of filter-aid were added. To this solution was added a solution of 8.5 g. (0.05 mole) of silver nitrate in 20 ml. of acetonitrile. The yellow precipitate was removed by suction filtration and washed with two 25-ml. portions of acetonitrile. To the combined acetonitrile filtrate was added a solution of 5.4 g. (0.04 mole) of phenylacetic acid and 3.7 g. of aniline (0.04 mole) in 20 ml. of acetonitrile. The temperature rose rapidly from 30 to 45°, then fell slowly to room temperature. After several hours the mixture was poured into 200 ml. of ice–water, and a solid separated. It was recovered by suction filtration and dried. The dry solid amounted to 5.4 g. (64%), m.p. 113–117°. Recrystallization from 25 ml. of 95% ethanol gave 4.1 g. of pure phenylacetanilide, m.p. 115.5–117.5° (lit.,[17] m.p. 116–117°).

S-Methyl N-(4-Ethoxycarbonyl)phenylthiolcarbamate.—A solution of 41.3 g. (0.25 mole) of ethyl *p*-aminobenzoate and 25.4 g. (0.25 mole) of triethylamine in 50 ml. of acetonitrile was added with stirring and cooling to a solution of 27.4 g. (0.25 mole) of methyl chlorothiolformate in 25 ml. of acetonitrile. The mixture was allowed to stand for 1 hr., then was poured into 500 ml. of ice–water. The solid which separated was recovered by suction filtration and dried under vacuum. The crude S-methyl N-(4-ethoxycarbonyl)phenylthiolcarbamate amounted to 23.0 g. (96%), m.p. 118–122°. Recrystallization from acetonitrile gave a pure sample, m.p. 121–123°.

Anal. Calcd. for $C_{11}H_{13}O_3NS$: C, 55.21; H, 5.48; N, 5.85; S, 13.40. Found: C, 55.27; H, 5.54; N, 5.75; S, 13.47.

1-Allyl-3-(4-ethoxycarbonyl)phenylurea.—To a solution of 9.6 g. (0.04 mole) of S-methyl N-(4-ethoxycarbonyl)phenylthiolcarbamate and 4.6 g. (0.08 mole) of allylamine in 50 ml. of acetonitrile was added a solution of 6.8 g. (0.04 mole) of silver nitrate in 15 ml. of acetonitrile. Cooling was required to hold the temperature between 30 and 40°. The yellow precipitate was recovered by suction filtration, washed with three 25-ml. portions of acetonitrile, and dried. The filtrate was evaporated to half volume and poured into 400 ml. of ice–water. The solid was recovered by suction filtration and dried. It amounted to 8.9 g., m.p. 109–120°. An additional 0.3 g. was recovered by extracting the silver methyl mercaptide with 25 ml. of boiling ethanol and pouring the filtrate into water. A portion of the product was recrystallized from ethanol to give pure 1-allyl-3-(4-ethoxycarbonyl)phenylurea, m.p. 121–122.5° (lit.,[18] m.p. 120°).

O-Ethyl N-(4-Ethoxycarbonylphenyl)carbamate.—To a solution of 9.6 g. (0.04 mole) of S-methyl N-(4-ethoxycarbonylphenyl)-thiolcarbamate and 5.1 g. (0.05 mole) of triethylamine in 75 ml. of absolute ethanol was added a solution of 10.9 g. (0.04 mole) of mercuric chloride in 40 ml. of absolute ethanol. A white solid precipitated, and the temperature rose from 30 to 50°. After 1.5 hr. the solid was recovered by suction filtration and washed with 50 ml. of ethanol. Hydrogen sulfide was bubbled through the filtrate for a few minutes; a small amount of black solid was removed by suction filtration. The filtrate was evaporated to about half volume under reduced pressure, and considerable solid crystallized. The solid was recovered by suction filtration and dried, and the filtrate was poured into 300 ml. of water. More solid separated, and was recovered by suction filtration and dried. The pure O-ethyl N-(4-ethoxycarbonylphenyl)carbamate from alcohol amounted to 3.8 g., m.p. 130–131.5° (lit.,[19] m.p. 130°, 131–132°). The less pure material from water amounted to 3.8 g., m.p. 124–126.5°. The infrared spectra of these two solids were identical. An additional 1.3 g., m.p. 130–132°, was recovered by extracting the methylmercaptomercuric chloride with 50 ml. of boiling ethanol and pouring the ethanol solution into 250 ml. of water. After this treatment the methylmercaptomercuric chloride weighed 10.8 g. (96%). The total recovery of O-ethyl N-(4-ethoxycarbonylphenyl)carbamate was 8.9 g. (94%).

Ethyl 3-Isothiocyanatopropionate.—A solution of 112.2 g. (2.0 moles) of potassium hydroxide and 89.1 g. (1.0 mole) of β-alanine in 250 ml. of water was stirred for 2.5 hr. with 76.1 g. (1.0 mole) of carbon disulfide. To the resulting homogeneous solution was added 104.7 g. (0.95 mole) of ethyl bromide, and the mixture was stirred for 3 hr. Enough heat was evolved to cause the ethyl bromide to reflux gently. A small amount of insoluble oil was removed by extraction with 100 ml. of ether, and the aqueous solution was acidified with 5 *N* hydrochloric acid. The oil which separated was extracted into 200 ml. of ether, and the ether solution was dried over anhydrous magnesium sulfate. Evaporation of the ether left 124.5 g. (81%) of crude 3-(S-ethyldithiocarbamoyl)propionic acid. The acid was taken up in 356 g. of absolute ethanol and 7.7 g. of *p*-toluenesulfonic acid was added. The solution was heated under reflux for 15 hr., then half the ethanol was evaporated under reduced pressure. The residue was poured into 1 l. of water, and 10% sodium carbonate solution was added until the pH was 8. The oil which separated was extracted into 150 ml. of ether, and the ether solution was dried over anhydrous magnesium sulfate. Evaporation of the ether left 105.6 g. (72%) of crude ethyl 3-(S-ethyldithiocarbamoyl)propionate.

A solution of 18.1 g. (0.10 mole) of this ester and 10.1 g. (0.10 mole) of triethylamine in 30 ml. of acetonitrile was treated with a

---

(13) All melting and boiling points are uncorrected.

(14) Microanalysis by Galbraith Laboratories, Inc., Knoxville 21, Tenn.

(15) W. J. S. Naunton, *J. Soc. Chem. Ind. Japan*, **45**, 376 T (1926).

(16) H. Tieckelmann and H. W. Post, *J. Org. Chem.*, **13**, 268 (1948).

(17) A. Reissert and A. More, *Ber.*, **39**, 3298 (1906).

(18) H. Thoms and K. Ritsert, *Ber. pharm. Ges.*, **31**, 65 (1921).

(19) (a) H. King and W. O. Murch, *J. Chem. Soc.*, **125**, 2595 (1924); (b) S. Basterfield and H. N. Wright, *J. Am. Chem. Soc.*, **48**, 2367 (1926).

solution of 17.0 g. (0.10 mole) of silver nitrate in 30 ml. of acetonitrile. The precipitate was removed by suction filtration, washed with two 10-ml. portions of acetonitrile, and dried. The dry silver ethyl mercaptide amounted to 17.0 g. (theory 16.9 g.). Most of the acetonitrile was evaporated from the filtrate, and 50 ml. of water was added to the residue. The oil which separated was extracted into two 50-ml. portions of ether, and the solution was dried over anhydrous magnesium sulfate. Evaporation of the ether left 10.5 g. (66%) of crude ethyl isothiocyanatopropionate. Distillation under reduced pressure gave 8.4 g. (53%) of purified material, b.p. 59.5–61° (0.2 mm.), n^{27}_D 1.4970. Redistillation gave pure ethyl 3-isothiocyanatopropionate, b.p. 58.5–60° (0.2 mm.), n^{27}_D 1.4983, d^{20}_4 1.114. Because the physical properties of this material did not agree well with those reported in the literature[20] [b.p. 92–94° (0.04 mm.), n^{25}_D 1.4904, d^{20}_4 1.132], the compound was analyzed.

Anal. Calcd. for $C_6H_9O_2NS$: C, 45.26; H, 5.70; N, 8.80; S, 20.14. Found: C, 45.43; H, 5.63; N, 8.68; S, 20.39.

1-Cyclohexyl-3-(2-ethoxycarbonylethyl)-2-thiourea.—A solution of ethyl 3-isothiocyanatopropionate in 150 ml. of acetonitrile prepared as described above from 61.1 g. (0.324 mole) of ethyl 3-(S-ethyldithiocarbamoyl)propionate was treated with 32.2 g. (0.324 mole) of cyclohexylamine. The temperature rose from 27 to 76°. After 1 hr. the reaction mixture was poured into 500 ml. of cold water. An oil separated and coagulated to a solid when the mixture was neutralized with 15 ml. of 5 *N* hydrochloric acid. After recovery by suction filtration and drying, the crude 1-cyclohexyl-3-(2-ethoxycarbonylethyl)-2-thiourea amounted to 52.1 g. (64%). Two recrystallizations from 1:1 benzene–petroleum ether gave 19.9 g. of brownish solid, m.p. 53–58°. A portion was recrystallized twice more from 1:1 benzene–petroleum ether to give pure white 1-cyclohexyl-3-(2-ethoxycarbonylethyl)-2-thiourea, m.p. 56–60°.

Anal. Calcd. for $C_{12}H_{22}ON_2S$: C, 55.78; H, 8.38; N, 10.85; S, 12.41. Found: C, 55.58; H, 8.34; N, 10.69; S, 12.52.

---

[20] D. L. Garmaise, P. Schwartz, and A. F. McKay, *J. Am. Chem. Soc.*, **80**, 3332 (1958).

Reactions of Dicyanoacetylene

C. D. WEIS

E. I. du Pont de Nemours & Co., Inc., Explosives Department, Experimental Station, Wilmington, Delaware

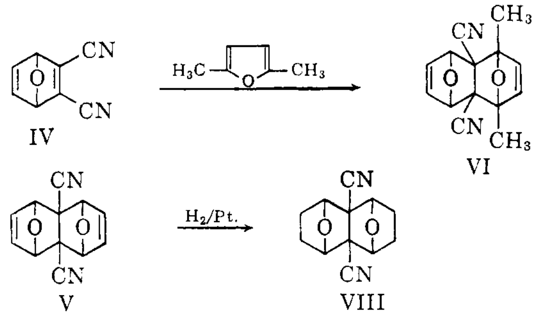
Received July 20, 1962

Dicyanoacetylene proved to be a highly reactive acetylenic dienophile. 1,4- Addition to durene gave the bicyclooctatriene skeleton. Other reactions with benzonitrile oxide, mercuric chloride, and diazomethane have been studied.

Literature reports on the reactivity of dicyanoacetylene (I) and its reaction products are noteworthy for their paucity. Only the addition of hydrogen chloride, ammonia, some amines,[1] and the Diels–Alder reaction with cyclopentadiene[2] have been reported. More recently it has been shown that dicyanoacetylene exhibited an exceptional reactivity as an acetylenic dienophile toward a number of 3,4-negatively substituted furan derivatives.[3] Its nature as a strong dienophile is further attested by the fact that fumaronitrile or tetracyanoethylene failed to undergo diene reaction with these 3,4-substituted furan derivatives as well in solution as in a solvent free phase.[3] Acetylene dicarboxylic acid[4] or its methyl ester[5] on the other hand may serve as a dienophile in a number of reactions, but the yields are not so good as with dicyanoacetylene. Hexafluoro-2-butyne, whose dienophilic activity was demonstrated even in the special case of 1,4- additions to benzene derivatives,[6] also underwent a facile diene reaction with 3,4-negatively disubstituted furan derivatives.[7] However, it led to an unstable adduct which underwent a retrodiene reaction as soon as it formed. In general, Diels–Alder reactions with hexafluoro-2-butyne require a higher temperature[6] than the ones with dicyanoacetylene.

The diene reaction of dicyanoacetylene with furan was of some interest because the tetracyclic system of 1,4,5,8-diepoxy-4a,8a-dicyano-1,4,4a,5,8,8a-hexahydronaphthalene(V) is formed with unusual ease.

The two components gave in molar ratios a mixture of the 1:1 adduct 1,4-epoxy-2,3-dicyanocyclohexa-2,5-diene (IV) and the 2:1 adduct (V). A 2:1 ratio of the starting materials led quantitatively to structure V at room temperature.



IV VI V VIII

IV reacted with a second mole of furan and yielded again the tetracyclic system (V) or, with 2,5-dimethylfuran as diene, 1,4-dimethyl-4a,8a-dicyano-1,4,5,8-diepoxy-4a,5,8,8a-tetrahydronaphthalene (VI) was obtained.

The structure of all these products was supported by the n.m.r. and infrared spectra which showed them to be regular diene adducts.

1,4,5,8-Diepoxy-4a,8a-dicyano-1,4,4a,5,8,8a-hexahydronaphthalene (V) was hydrogenated and consumed two moles of hydrogen giving the tetrahydro derivative 1,4,5,8-diepoxy-4a,8a-dicyanodecalin (VIII).

Since the attack of the 1:1 adduct (IV) by a second mole of furan occurs at the more hindered side, the formation of these diene adducts seems governed by the strong electron-withdrawing effect of the nitrile substituents. It seems, therefore, not limited to compounds with an exceptionally low electron density at the double bond such as is found in 2,3-dicyanobenzoquinone.[8] While dicyanoacetylene yielded this tetra-

---

[1] (a) C. Moureu and J. C. Bongrand, *Compt. rend.*, **158**, 1092 (1920); (b) *Ann.*, **14**, 5 (1920).

[2] A. T. Blomquist and E. C. Winslow, *J. Org. Chem.*, **10**, 149 (1945).

[3] C. D. Weis, *ibid.*, **27**, 3520 (1962).

[4] H. Stockmann, *ibid.*, **26**, 2025 (1961).

[5] O. Diels and S. Olsen, *J. prakt. Chem.*, **156**, 289 (1940).

[6] C. G. Krespan, B. C. McKusick, and T. L. Cairns, *J. Am. Chem. Soc.*, **83**, 3428 (1961).

[7] C. D. Weis, *J. Org. Chem.*, **27**, 3693 (1962).

[8] H. D. Hartzler and R. E. Benson, *ibid.*, **26**, 3507 (1961).