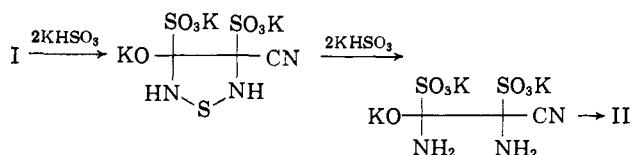


formic acid and ammonia, plus potassium sulfite which further interacts with traces of cyanide to generate potassium thiosulfate and potassium thiocyanate.

The formation of II from the cyanohydroxythiadiazole I follows logically from nucleophilic attack by bisulfite at the electron deficient carbon atoms, giving an intermediate product similar to that observed on addition of bisulfite to quinoxaline⁵ (IV). The resultant substituted thiadiazolidine ring is then reduced



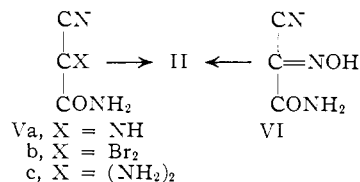
at the sulfur-nitrogen bonds by additional bisulfite. An analogy to this proposed mechanism is the reduction of 3,5-diamino-1,2,4-thiadiazole to amidinothiourea by aqueous sulfur dioxide.⁶ Cleavage of both adjacent sulfur bonds releases sulfur which reacts immediately with bisulfite residues to form trithionate.⁷ The unstable organic moiety then expels one sulfonate group, which rapidly autoxidizes to sulfate, and stabilization is achieved as the salt of aminocarbamoyl-cyanomethanesulfonic acid (II).



The formation of this novel product by hydrolysis of the KCN-SO₂ product prompted a reinvestigation of the reaction of potassium cyanide and sulfur dioxide in water. Despite the comments of von Pechmann and Manck, the claims of Etard⁹ to have isolated the hydrated form of potassium cyanosulfinate are still reported by Williams¹⁰ and by Mellor.¹¹ Reaction under conditions approximating those of Etard yielded a colorless crystalline product having all the properties attributed to *le cyanosulfite de potassium*.⁹ Elemental analysis and infrared comparison with an authentic sample confirmed the identity of this product as dipotassium aminomethionate (III).

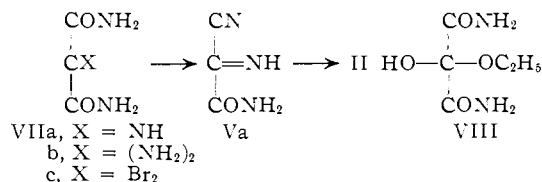
Synthesis of Substituted Aminomethanesulfonates.—Structural confirmation of II was not achieved by direct synthesis. Since alkali metal bisulfites are capable of adding at the carbon-nitrogen multiple bond of many unsaturated compounds to form sulfonic acids—for example, potassium cyanide,⁴ potassium cyanate,¹² and aliphatic isothiocyanates¹³—experiments were designed so that the final stage would involve such addition. Accordingly, the most con-

venient intermediate would be iminocyanacetamide (Va). The dibromo derivative Vb was prepared in quantitative yield by bromination of cyanacetamide,¹⁴ but conversion to Vc or directly to the imine Va by reaction with ammonia under various conditions in absolute methanol or in tetrahydrofuran led only to the formation of intractable colored solids. This behavior appears to be similar to the formation of polymers reported in the reaction of bromomalononitrile and ammonia.¹⁵



An alternative route of some promise seemed to be the reductive addition of bisulfite across the oxime group of isonitrosocyanacetamide (VI). This compound was readily prepared¹ but no reaction occurred with aqueous solutions of potassium bisulfite even on heating, or in the presence of magnesium turnings. In the latter case degradation of reactants occurred.

According to Conrad and Bruckner¹⁶ an ill-defined compound, probably iminomalonamide (VIIa), is formed on thermal decomposition of diaminomalonamide (VIIb). A third route to II was therefore available through partial dehydration of VIIa to Va, followed by bisulfite addition. Diaminomalonamide was smoothly converted to the analytically pure diamino derivative VIIb in 70% yield on exposure to methanolic ammonia at room temperature. Additional crops of crystals were colored mauve and were



of different character, possibly a dimer of iminomalonamide.¹⁷

Mild pyrolysis of the diamine VIIb led to evolution of ammonia and formation of a yellow-green powder analyzing correctly for the imine VIIa. In practice the reaction was most easily performed by heating in boiling benzene or acetonitrile from which the product separates directly as pale yellow needles. Use of ethanol gave incomplete conversion in 1 hr. and prolonged heating led to formation of a product analyzing as the monoethyl ether of dihydroxymalonamide (VIII). Careful exclusion of moisture from the reaction in boiling ethanol gave instead the same product as that obtained after prolonged exposure of dibromomalonamide to methanolic ammonia.

Attempts at converting iminomalonamide to Va with conventional dehydrating agents were unsuccessful, and no reaction occurred under the mild conditions required for amide dehydration using triphenylphos-

(5) F. W. Bergstrom and R. A. Ogg, Jr., *J. Am. Chem. Soc.*, **53**, 245 (1931).

(6) F. Kurzer, *J. Chem. Soc.*, 2288 (1955).

(7) In general polythionic acids are formed whenever sulfurous acid comes in contact with finely divided sulfur. Usually a mixture of polythionic acids is obtained, but under some conditions single products are formed. For a review article on the formation of potassium trithionate see ref. 8.

(8) M. Goehring, *Fortschr. chem. Forsch.*, **2**, 444 (1952).

(9) A. Etard, *Compt. rend.*, **88**, 649 (1879).

(10) H. E. Williams, "Cyanogen Compounds," 2nd Ed., Arnold, London, 1949, p. 94.

(11) J. W. Mellor, "A Comprehensive Treatise on Inorganic and Theoretical Chemistry," Vol. X, 1st Ed., Longmans, 1944, p. 224.

(12) J. D. Riedel, *Friedl.*, **12**, 103 (1916); German Patent 290,426 (1916).

(13) S. Petersen, *Ann.*, **562**, 205 (1949).

(14) B. M. Gupta and J. F. Thorpe, *J. Chem. Soc.*, **121**, 1896 (1922); B. C. Hesse, *Am. Chem. J.*, **18**, 723 (1896).

(15) W. Ruske and E. Ruske, *Ber.*, **91**, 2496 (1958).

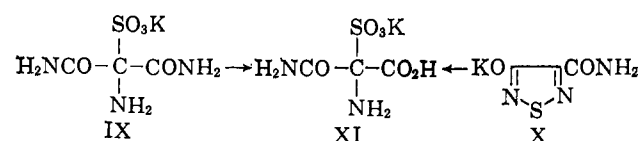
(16) M. Conrad and C. Bruckner, *ibid.*, **24**, 2993 (1891).

(17) S. Ruhemann and K. J. P. Orton, *J. Chem. Soc.*, **67**, 1002 (1895), reported quantitative conversion of VIIc to diaminomalonamide using concentrated aqueous ammonia at room temperature for several days.

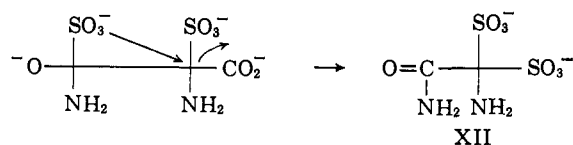
phonium bromide¹⁸ or using trichloroacetonitrile.¹⁹ Addition of bisulfite to iminomalonamide occurred smoothly in aqueous solution at room temperature. The resultant potassium aminodicarbamoylmethanesulfonate (IX) was similar spectroscopically to II, without the nitrile absorption, but interconversion of these compounds was not achieved.

It was anticipated that the structure of II could be confirmed indirectly by isolation of the dicarbamoyl salt IX from analogous bisulfite degradation of 3-hydroxy-1,2,5-thiadiazole-4-carboxamide (X), a derivative readily available by partial hydrolysis of I.¹ Surprisingly, the sole product obtained from such a reaction was the sparingly water-soluble potassium acid salt of X.

Apparently the electron deficiency of the 1,2,5-thiadiazole ring is extremely sensitively balanced, and the different electron-withdrawing properties of amide rather than nitrile make the difference as to whether or not bisulfite can add to the thiadiazole ring carbon atoms. Bisulfite cleavage of the thiadiazole ring in the hydroxyamide was achieved in poor yield by performing the reaction under reflux. However, the degraded product was not the anticipated dicarbamoyl derivative IX but the monopotassium salt of aminocarbamoylcarboxymethanesulfonate (XI) derived by hydrolysis of one of the amide groups. Proof of this structure was obtained by hydrolysis of the synthetic dicarbamoyl salt IX to XI in boiling water.



Additional Aminomethanesulfonates.—An alternative method of obtaining the salt XI seemed likely by bisulfite reduction of the corresponding thiadiazole-hydroxycarboxylic acid. Once again the anticipated degradation product was not obtained. Evolution of carbon dioxide occurred immediately on mixing warm aqueous solutions of potassium pyrosulfite and the hydroxy acid dipotassium salt. The colorless crystalline salt, isolated by the usual method of fractional crystallization, had the empirical formula $\text{C}_2\text{H}_4\text{K}_2\text{N}_2\text{O}_7\text{S}_2$. On the basis of the analytical data and the close relationship of its infrared spectrum to both salt IX and dipotassium aminomethionate (III), the product has been assigned tentatively the structure of dipotassium aminocarbamoylmethionate (XII). Formation of salt XII may be explained by preferential expulsion of the carboxyl group from the bisulfite addition product, followed by migration of one sulfonate group enabling formation of the carbamoyl group.



(18) L. Horner, H. Oediger, and H. Hoffman, *Ann.*, **626**, 26 (1959).

(19) The possibility of employing the highly reactive trichloroacetonitrile as an amide dehydrating agent was suggested by Dr. R. C. Blume of the Textile Fibers Department, E. I. du Pont de Nemours and Co., Inc.

In an attempt to prove that addition of bisulfite occurs prior to elimination of carbon dioxide, an aqueous solution of the decarboxylated 3-hydroxy-1,2,5-thiadiazole was treated with bisulfite solution. No indication of the formation of salt XII was obtained. Instead a strong odor of hydrogen cyanide was detected from the reaction mixture. A colorless crystalline product was isolated having an infrared spectrum similar to the other aminomethanesulfonates, but no structure could be assigned to this product having the empirical formula of $\text{C}_2\text{H}_4\text{K}_2\text{N}_2\text{O}_5\text{S}_3$. The only other products isolated from this reaction were potassium sulfate and potassium dithionate.

Two other compounds of unproven composition were isolated from reactions involving hydrolysis of one batch of KCN-SO₂ reaction product. The typical KCN-SO₂ sample was treated with water in the usual way and the warmed solution divided in half; one part was treated with ethanol and the other with acetone; both mixtures were kept at room temperature for the unusually long period of 72 hr. before work-up. On the basis of analytical data and the similarity of their infrared spectra to those of known compounds II and III, the crystalline salts obtained from these reactions were provisionally assigned the structures XIII and XIV, respectively. They are assumed to be degradation products of the initially formed aminocarbamoyl-



cyanomethanesulfonate. That degradation of II does occur on prolonged contact with water was shown by keeping an aqueous solution of KCN-SO₂ product at room temperature for 9 weeks after which period the only product isolated was potassium sulfate.

Despite the considerable volume of literature dealing with methanesulfonates and substituted methionates, there are very few references to compounds of this type substituted by amino, carbamoyl, or nitrile groups. The best known examples are the aminomethionate salts of von Pechmann and Manck,⁴ and aminomethanesulfonic acid, prepared from formaldehyde, bisulfite, and ammonia as an intermediate in the preparation of Rongalite.²⁰ Cyanomethanesulfonic acid has been prepared recently²¹ by sulfonation of acetonitrile, and secondary carbamoylcyanomethionates were prepared by a similar method by sulfonation of N-substituted cyanoacetamides.²² The only method of introducing an amino group is that consequential to the addition of bisulfite across a carbon-nitrogen multiple bond. The novelty of the substituted products reported in this paper depends upon the fortuitous molecular arrangement of the 3-hydroxy-1,2,5-thiadiazole system and the facility with which it undergoes the nucleophilic and reductive attack by aqueous solutions of bisulfite.

Experimental²³

Hydrolysis of KCN-SO₂ Reaction Product. Qualitative Analysis.—A sample of KCN-SO₂ reaction product¹ (prepared at

(20) K. Reinking, E. Dehnel, and H. Labhardt, *Ber.*, **38**, 1069 (1905).

(21) A. P. Terent'ev, L. A. Yanovskaya, A. M. Berlin, and E. A. Borisov, *Chem. Abstr.*, **49**, 8092h (1955).

(22) K. G. Naik and M. B. Amin, *J. Indian Chem. Soc.*, **5**, 579 (1928).

(23) Analyses were performed by Micro-Analysis, Inc., Marshallton, Del.

50° for 5 hr.; 97 wt. % SO₂ uptake) was dissolved in water, accompanied by the usual slight evolution of hydrogen cyanide. Removal of traces of insoluble black powder gave a yellow, slightly acid solution (pH *ca.* 5.5). Treatment of a sample with a neutral solution of barium chloride gave a yellow-white precipitate accompanied by enhanced acidity of the solution, indicative of the presence of bisulfite ion. Treatment with copper sulfate solution precipitated a yellow-orange solid identified by comparative infrared analysis as the thiazazole copper salt. Neither of the above tests gave positive results after the solution was more than a few hours old.

Treatment of a fresh solution with aqueous barium hydroxide and removal of excess barium ions by addition of sulfuric acid gave a colorless filtrate which gave positive tests for the presence of thiocyanate ions (red coloration on addition of ferric chloride) and trithionate ions (milky precipitate with mercuric chloride). Treatment of a further sample with silver nitrate and removal of excess silver ions with hydrochloric acid gave a colorless solution which gave positive tests for the presence of sulfate ions (precipitate with barium hydroxide, and pink color with phenolphthalein on evaporation of a solution in the presence of barium carbonate). The potassium salts of all three anions were isolated from larger scale experiments and identified by their infrared spectra: $\lambda_{\text{max}}^{\text{KBr}} \text{SCN}^-$: 4.86 (vs), 10.30 (w), 10.48 (w), 13.32 μ (m); $\lambda_{\text{max}}^{\text{KBr}} \text{SO}_4^{2-}$: 8.90 (b; vs), 10.15 μ (w); $\lambda_{\text{max}}^{\text{KBr}} \text{S}_3\text{O}_6^{2-}$: 8.10 (b; vs), 8.40 (m), 9.50 (s), 9.76 μ (vs).

Isolation of Potassium Aminocarbamoylcyanomethanesulfonate²⁴ (II).—KCN-SO₂ product (36 g.) was stirred with 125 ml. of water at 55° for 10 min., filtered from traces of insoluble black material, and the filtrate diluted with 125 ml. of warm ethanol. After 24 hr. at 0° the yellow solution had deposited a dark brown granular mass covered with long, light-yellow needles. The yellow needles were separated mechanically and recrystallized twice from water-ethanol. The almost colorless needles were characterized by spot tests and by infrared analysis as potassium trithionate.

Anal. Calcd. for K₂S₃O₆: K, 28.9; S, 35.6. Found: K, 29.9; S, 35.1.

The residual colored deposit after two recrystallizations from water-ethanol (charcoal decolorization) yielded large colorless rhombs, not melting below 300°.

Anal. Calcd. for C₃H₄KN₂O₄S·H₂O: C, 15.3; H, 2.57; K, 16.6; N, 17.9; S, 13.6. Found: C, 15.3; H, 2.61; K, 16.4; N, 17.8; S, 13.7.

Its usual existence as a monohydrate was demonstrated by drying in an Abderhalden drying pistol at 100° and 1 mm. pressure for 15 hr. It gave no color with ferric chloride, did not reduce iodine or potassium permanganate, and was unaffected on treatment with solutions of silver nitrate, barium chloride, mercuric chloride, or copper sulfate. The infrared spectrum exhibited complex (N-H) absorption at 2.85, 2.90, 2.98, and 3.06 μ . Amide carbonyl absorption occurred at 5.80 μ , unconjugated nitrile absorption at 4.40 μ , and characteristic splitting of sulfonate (S=O) vibrations at *ca.* 8.0 and *ca.* 9.4 μ .

Anal. Calcd. for C₃H₄KN₂O₄S: C, 16.6; H, 1.85; K, 18.0; N, 19.3; S, 14.8. Found: C, 16.5; H, 1.87; K, 17.8; N, 19.2; S, 14.9.

Hydrolysis of Synthetic Equimolecular Pyrosulfite-Thiazazole Mixture.—A mixture of 3-cyano-4-hydroxy-1,2,5-thiazazole potassium salt (0.85 g.) and potassium pyrosulfite (1.15 g.) was dissolved in 25 ml. of water, left at room temperature for 48 hr., then evaporated to dryness at room temperature under reduced pressure. Extraction of the yellow residue with boiling acetonitrile (three 25-ml. portions) removed unreacted thiazazole (410 mg., 48% starting material) identified by its infrared spectrum. The insoluble residue (1.52 g.) was identical with that obtained by similar treatment of a sample of KCN-SO₂ reaction product. The infrared spectrum showed the presence of potassium sulfate, potassium trithionate, and the methanesulfonate II. Under similar conditions potassium pyrosulfite was converted to a mixture containing substantial amounts of potassium sulfate and some potassium sulfite, identified by infrared and chemical analyses.

Hydrolysis of Synthetic 2:1 Pyrosulfite-Thiazazole Mixture.—A 1:2 molecular mixture (21.0 g.) of cyanohydroxythiazazole potassium salt (8.25 g.) and potassium pyrosulfite (22.23 g.) was dissolved in 75 ml. of water at 75°, stirred for 5 min., and treated with 20 ml. of ethanol. The white precipitate

which formed was collected (1.30 g.) and identified as potassium sulfate.

Colorless needles separated as the solution cooled, and after storing at 0° overnight the crystalline material (10.3 g.) was collected and identified by infrared as the methanesulfonate II contaminated with some potassium trithionate. Further crops of crystals consisted of potassium trithionate and potassium sulfate. Recrystallization of the contaminated organic product from water-ethanol gave 6.25 g. (77%) of spectroscopically pure methanesulfonate as its monohydrate.

Reaction of Potassium Cyanide and Sulfur Dioxide in Water (Etard's Reaction).—A 40% aqueous solution of potassium cyanide (100 ml.) was cooled to -10° and treated with a slow stream of sulfur dioxide so that the reaction temperature was maintained at 0 ± 5°. After 15 min. the clear solution solidified to a white crystalline mass. The flow of sulfur dioxide was stopped and liquid hydrogen cyanide (10 ml.) was added to replace any removed by the gas stream. The mixture was lightly stoppered and allowed to warm to room temperature. After 2 hr. solution was complete, giving a pale-yellow liquid of pH 5.5. Colorless crystals began to separate 3 hr. later. After 22 hr. the reddish liquid phase (pH 8.5) was decanted from the crystalline mass which was collected and washed with ice-cold water, ethanol, and ether. The colorless rhombohedra (23.3 g.) had all the properties described by Etard for "potassium cyanosulfite" and were identified by analysis and infrared comparison with an authentic sample as dipotassium aminomethionate (III). The infrared spectrum showed NH₂ absorption at 2.90, 3.0, and 3.08 μ , weak C-H at 3.40 μ , and strong sulfonate (S=O) at 8.20, 9.35, and 9.70 μ .

Anal. Calcd. for CH₃K₂NO₆S·H₂O: C, 4.2; H, 1.77; N, 4.9; S, 22.4. Found: C, 4.3; H, 1.95; N, 5.1; S, 22.4.

Acidification of an aqueous solution of the dipotassium salt with excess concentrated hydrochloric acid precipitated the pure monopotassium salt.

Anal. Calcd. for CH₄KNO₆S₂: C, 5.2; H, 1.76; N, 6.1; S, 28.0. Found: C, 5.4; H, 1.83; N, 5.6; S, 27.5.

Acid Hydrolysis of Potassium Aminocarbamoylcyanomethanesulfonate.—The monohydrate (2.0 g.) was dissolved in 10% aqueous hydrochloric acid (20 ml.) at room temperature. The odor of hydrogen cyanide was distinct after 6 hr. The presence of cyanide ion was confirmed by evaporating a small portion to dryness in the presence of yellow ammonium sulfide and obtaining a strong positive reaction for thiocyanate (red color with ferric chloride.) After 72 hr. at room temperature the reaction mixture was diluted with ethanol and evaporated to dryness at room temperature and 1 mm. pressure. The white residue (2.02 g.) was predominantly ammonium chloride. Extraction with 50 ml. of warm ethanol removed some solid (200 mg.) having an infrared spectrum similar to that of glycine hydrochloride; the prominent spectral bands were: hydrolysis product in KBr: 2.8-3.4 (b; vs), 5.7-5.9 (b; vs), 7.0-7.2 (b; vs), 7.9-8.1 (b; vs), 9.46 (s), 11.1 (m), 11.7 (m) μ ; glycine hydrochloride in KBr: 2.88-3.0 (s), 3.25-3.45 (vs), 5.75 (vs), 6.70 (m), 8.0 (vs), 9.50 (s), 11.00 (m), 11.65 (m) μ . An attempt was made to compare the two samples by paper chromatography.²⁵ Samples were spotted on Whatman No. 1 filter paper strips, run for 16 hr. in a 1-butanol-water-acetic acid (5:1:4) mixture, and the dried strips developed with ninhydrin. The principal spot in all cases had an *R_f* value of 0.26-0.31 marred by excessive salt tailing.

Synthesis of Potassium Aminodicarbamoylmethanesulfonate (IX). A. Dibromomalonamide was prepared as described by Freund with the modified procedure due to Whiteley, *et al.*²⁶ The dibromo compound, obtained in 83% yield, m.p. 204.5-205.5° (reported²⁶ m.p. 206°), was used without further purification.

Anal. Calcd. for C₃H₄Br₂N₂O₂: Br, 61.5. Found: Br, 61.4.

B. Diaminomalonamide.—A suspension of dibromomalonamide (40.0 g.) in 470 ml. of absolute methanol was rapidly stirred and cooled to -25°. Six 25-ml. aliquots of absolute methanol saturated with dry ammonia gas at 0° were added without any observed rise in temperature, and the reaction mixture was kept at 0° for 3 days. Unchanged dibromomalonamide (8.45 g.) was then collected and the colorless solution stored at 0° for another 2 days. The reaction mixture was allowed to warm to

(25) These experiments were performed by Mr. L. R. DiMaio of this laboratory.

(26) M. Freund, *Ber.*, **17**, 780 (1884); J. V. Backes, R. W. West, and M. A. Whiteley, *J. Chem. Soc.*, **119**, 359 (1921).

(24) Developed from some unpublished experiments by Dr. W. C. Smith.

room temperature and the colorless, thick needles which slowly deposited were collected periodically during 3 days, until the solution and deposits were colored mauve.

The colorless crystals of the diamine (10.45 g., 65%) required no further purification. The crystals discolored on heating above 140° and decomposed at 170° (*cf.* iminomalonaldehyde).

Anal. Calcd. for $C_3H_8N_2O_2$: C, 27.3; H, 6.10; N, 42.4. Found: C, 27.3; H, 6.00; N, 42.1.

The final mauve to gray deposits yielded after crystallization from water (charcoal treatment) a yellow powder not melting below 320°.

Anal. Calcd. for $C_3H_8N_3O_2$: C, 31.0; H, 5.21; O, 27.6. Found: C, 31.4; H, 4.91; O, 27.2.

C. Iminomalonaldehyde.—A suspension of diaminomalonaldehyde (3.77 g.) in anhydrous benzene (200 ml.) was heated under reflux (CaCl₂ guard tube) for 16 hr. The colorless crystals of diamine disappeared leaving a yellow-green microcrystalline deposit of analytically pure iminomalonaldehyde (3.19 g., 97%), m.p. 170–171° dec., which recrystallized from acetonitrile as pale yellow needles.

Anal. Calcd. for $C_3H_5N_3O_2$: C, 31.3; H, 4.38; O, 27.8. Found: C, 31.1; H, 4.42; O, 27.8.

The infrared spectrum showed λ_{max}^{KBr} 2.98, 3.10, and 3.15 μ (–NH and NH₂), 5.88 and 5.94 μ (amide C=O), and other major bands at 6.90, 7.75, 9.95, 10.10, 12.0, and 12.6 μ .

Slightly impure samples of the imine were obtained by heating diaminomalonaldehyde in ethanol for 1 hr. When the diamine was heated in ethanol on a steam bath for prolonged periods (16 hr.) no imine was obtained. A solution of the diamine (1.0 g.) in 200 ml. of ethanol became mauve after refluxing for 16 hr. Concentration of the solution to ca. 10 ml. gave a crystalline deposit (680 mg.) which after two recrystallizations from ethanol (charcoal treatment) yielded pure ethoxyhydroxydiaminomalonaldehyde as rosettes of colorless rods, m.p. 155–156° dec.

Anal. Calcd. for $C_3H_{10}N_2O_3$: C, 37.0; H, 6.21; N, 17.3; OEt, 27.8. Found: C, 36.8; H, 6.40; N, 17.5; OEt, 26.8.

Refluxing the diamine in absolute ethanol with exclusion of moisture for 16 hr. yielded instead an incompletely characterized blue-gray solid. Crystallization from water (charcoal treatment) gave a pale yellow powder not melting below 320°. The infrared spectrum, which was remarkably close to that of iminomalonaldehyde without the strong bands at 9.95 and 12.0 μ , was the same as that of the colored material isolated from the amination of dibromomalonaldehyde with methanolic ammonia.

Anal. Calcd. for $C_3H_8N_3O_2$: C, 31.0; H, 5.21; O, 27.6. Found: C, 30.7; H, 5.05; O, 27.5; OEt, nil.

D. Potassium Aminodicarbamoylmethanesulfonate (IX).—To a stirred solution of potassium pyrosulfite (1.3 g.) in 5 ml. of water at 10° was added finely powdered iminomalonaldehyde (1.25 g.). A mild exothermic reaction occurred and an additional 5 ml. of water was added to complete solution. After stirring for 5 min. excess ethanol (30 ml.) was added and the precipitated sulfonate was collected, washed, and dried (1.70 g., 67%). The product was recrystallized once from water–ethanol, yielding bundles of long, thin, colorless rods (1.1 g.).

Anal. Calcd. for $C_3H_8KN_3O_5S$: C, 15.3; H, 2.57; K, 16.6; N, 17.9; S, 13.6. Found: C, 15.5; H, 2.66; K, 16.6; N, 17.4; S, 13.5.

The infrared spectrum exhibited primary amide (N–H) at 2.95 and 3.05 μ . Amide carbonyl occurred at 5.90 μ and sulfonate (S=O) at 8.10, 8.30, and 9.50 μ . Anomalous weak nitrile absorption occurred at 4.60 μ .

Potassium Aminodicarbamoylcarboxymethanesulfonate (XI).

A. Aqueous Bisulfite Reduction of 3-Hydroxy-1,2,5-thiadiazole-4-carboxamide.—Solutions of 3-hydroxy-1,2,5-thiadiazole-4-carboxamide potassium salt (12.2 g.) in 75 ml. of water and of potassium pyrosulfite (30.0 g.) in 125 ml. of water were warmed to 75°, mixed, and heated under reflux for 1 hr. The hot reaction mixture was treated with 100 ml. of ethanol and the precipitated potassium sulfate (10.7 g.) was filtered off. The filtrate was cooled for 2 hr. at 0° and the colorless crystalline deposit (4.1 g.) collected and leached twice with 15-ml. portions of cold water. The water-soluble component was isolated and identified by its infrared spectrum as potassium dithionate, λ_{max}^{KBr} 8.00 (s), 8.25 (m), and 10.00 (s) μ .

Anal. Calcd. for $K_2S_2O_6$: S, 26.9. Found: S, 26.2.

The undissolved powder (0.87 g.) recrystallized from water–ethanol (20 ml. of 1:1 at 70°) giving clumps of colorless needles (0.75 g.) of aminodicarbamoylcarboxymethanesulfonic acid potassium salt. The infrared spectrum was similar to that of the

aminodicarbamoylcarboxymethanesulfonate without nitrile absorption, exhibiting (N–H) bands at 2.80 and 2.95 μ .

Anal. Calcd. for $C_3H_8KN_3O_5S$: C, 15.3; H, 2.13; K, 16.6; N, 11.9; S, 13.6. Found: C, 15.6; H, 2.29; K, 16.9; N, 12.2; S, 13.2.

On further cooling overnight the reaction mixture deposited a thick mat of minute cream needles (5.0 g.) of the hydroxythiadiazolecarboxamide potassium acid salt. The infrared spectrum showed absorption equivalent to the summation of bands from the hydroxyamide and its potassium salt except for a wide plateau of high absorption extending from 8.0 to 11.0 μ , a region where its components are transparent.

Anal. Calcd. for $C_3H_8N_3O_5S \cdot C_3H_2KN_3O_2S$: C, 22.0; H, 1.53; K, 11.9; N, 25.6; S, 19.5. Found: C, 22.3; H, 1.78; K, 12.6; N, 24.8; S, 19.0.

The residual reaction mixture was evaporated to dryness under reduced pressure and yielded unchanged thiadiazole amide as its potassium salt (5.2 g.).

B. Hydrolysis of Potassium Aminodicarbamoylmethanesulfonate (IX).—The dicarbamoylsulfonate (0.75 g.) in 25 ml. of water was heated under gentle reflux for 1 hr. and treated while hot with 100 ml. of ethanol. The dried precipitate (0.45 g.) was quickly leached with 5 ml. of cold water and the insoluble portion recrystallized from water–ethanol. The colorless clusters of needles (0.13 g.) exhibited the identical infrared spectrum with that of the thiadiazole amide degradation product.

Anal. Calcd. for $C_3H_8KN_3O_5S$: C, 15.3; H, 2.13; K, 16.6; N, 11.9; S, 13.6. Found: C, 15.5; H, 2.23; K, 16.4; N, 12.2; S, 13.4.

Aqueous Bisulfite Reduction of 3-Hydroxy-1,2,5-thiadiazole-4-carboxylic Acid.—3-Hydroxy-1,2,5-thiadiazole-4-carboxylic acid dipotassium salt (7.8 g.) in 30 ml. of water at 65° was added to a solution of potassium pyrosulfite (15.6 g.) in 40 ml. of water at 65°. There was an immediate evolution of carbon dioxide. The mixture was warmed to 70° during 5 min. and treated with ethanol (70 ml.) to precipitate potassium sulfate and some potassium dithionate (1.5 g.). After 4 hr. at room temperature the pale yellow mixture was filtered and the glistening colorless rods were collected (2.9 g.). A further, larger crop obtained after cooling to 0° overnight was grossly contaminated with inorganic salts and was not purified. The pure product was recrystallized once from water–ethanol giving colorless, hygroscopic rods.

Anal. Calcd. for $C_2H_4K_2N_2O_7S_2$: C, 7.74; H, 1.46; K, 25.2; N, 9.03; S, 20.7. Found: C, 7.71; H, 1.46; K, 25.4; N, 8.96; S, 20.7.

On the basis of its analysis this compound was assigned the structure of dipotassium aminodicarbamoylmethionate (XII). Its infrared spectrum was in accord with this assignment, exhibiting N–H absorption at 2.90 and 3.05 μ , amide carbonyl at 5.85 μ , and sulfonate (S=O) absorption at 8.20, 9.40, and 9.60 μ .

Aqueous Bisulfite Reduction of 3-Hydroxy-1,2,5-thiadiazole.—Following the above procedure, a solution of the hydroxythiadiazole potassium salt (3.5 g.) in 20 ml. of water at 60° was added to a solution of potassium pyrosulfite (9.8 g.) in 35 ml. of water at 65°. The mixture was heated on a steam bath for 5 min. and ethanol (25 ml.) added to precipitate potassium sulfate (3.6 g.). This was the only reduction experiment in which the filtered reaction mixture had an odor of hydrogen cyanide. After 4 hr. at room temperature a mass of colorless needles was collected (3.25 g.) which was characterized by its infrared spectrum as an amino-sulfonate contaminated with potassium sulfate and potassium dithionate. The mixture was purified by leaching out the organic component with small quantities of water and recrystallizing three times from water–ethanol. The resultant rosettes of colorless needles were shown to be free from inorganic salts by the infrared spectrum.

Anal. Calcd. for $C_2H_4K_2N_2O_8S_3$: C, 6.70; H, 1.12; K, 21.8; N, 7.82; S, 26.8. Found: C, 6.66; H, 1.36; K, 21.6; N, 7.85; S, 27.2.

The infrared spectrum appeared to be very similar to that of dipotassium aminodicarbamoylmethionate, showing N–H absorption at 2.90 and 3.00 μ , amide carbonyl at 6.00 μ , and strong sulfonate (S=O) at 8.20, 9.53, and 9.75 μ . No structural assignment was made.

Isolation of Salts XIII and XIV.—A sample of a typical KCN–SO₂ product (17.8 g., prepared at 50° for 5 hr.; 99 wt. % SO₂ uptake) was stirred with 50 ml. of water at room temperature for 15 min. The filtered solution was warmed to 70° and divided into equal portions A and B.

Sample A was treated with ethanol until cloudy and the filtered

solution left at room temperature for 72 hr. The dark brown crystalline deposit was collected and recrystallized from water-ethanol (charcoal decolorization) yielding light tan monoclinic needles. The infrared spectrum was similar to that of the sulfonate II, N-H at 2.65 and 2.80 μ , weak C-H at 3.30 μ , no carbonyl absorption, weak nitrile at 4.4 μ , and strong singlet sulfonate (S=O) bands at 7.80 and 9.30 μ .

Anal. Calcd. for $C_2H_3KN_2O_3S$: C, 13.8; H, 1.73; K, 22.5; N, 16.1; S, 18.4. Found: C, 13.9; H, 1.60; K, 22.7; N, 15.5; S, 18.6.

This product is postulated to be an hydrolysis product of potassium aminocarbamoylcyanomethanesulfonate (II) and is assigned the structure of potassium aminocyanomethanesulfonate (XIII).

Sample B was treated with acetone until cloudy and the filtered

solution was left at room temperature for 72 hr. A small yield of straw-colored needles was obtained which exhibited a much simpler infrared spectrum than that of salt II; N-H absorption appeared at 2.80 and 2.90 μ , no carbonyl absorption was present, a weak unconjugated nitrile at 4.4 μ , and multiple sulfonate (S=O) absorption at *ca.* 8.0 and 9.4 μ .

Anal. Calcd. for $C_2H_2K_2N_2O_6S_2$: C, 8.21; H, 0.69; N, 9.58; S, 21.9. Found: C, 7.86; H, 0.91; N, 9.60; S, 22.4.

On the basis of analytical and spectroscopic data, particularly by comparison with the spectrum of potassium aminocarbamoylmethionate, the compound is postulated to be the partial hydrolysis product dipotassium aminocyanomethionate (XIV).

When the above procedures were repeated and the period of time before work-up was extended to 9 weeks, the sole product isolated was potassium sulfate.

[CONTRIBUTION FROM THE ADVANCED ORGANIC CHEMICALS RESEARCH LABORATORY, ORGANIC CHEMICALS DIVISION, MONSANTO CHEMICAL CO., SAINT LOUIS, MO.]

The Mechanism of the Base-Catalyzed Addition of Thiols to Maleic Anhydride¹

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Rate data are presented for the base-catalyzed addition of thiols to maleic anhydride in xylene. Third-order kinetics have been observed, first order each in thiol, maleic anhydride, and triethylenediamine. Added product and radical inhibitor have no effect on the rate of thiol disappearance, which has no apparent activation energy. Spectroscopic studies show interaction between thiol and base, but not between thiol and maleic anhydride; the xylene solutions, however, are nonconducting. An inverse hydrogen isotope effect has been observed. The results are discussed in terms of an equilibrium between thiol and base to form an ion pair followed by the rate-limiting attack of thiolate anion on maleic anhydride.

Introduction

A previous report from this laboratory² was concerned with preparation of alkylthio and arylthio anhydrides achieved by the addition of thiols to anhydrides in the presence of basic catalysts under anhydrous conditions. The purpose of the present paper is to establish the mechanism of the addition reaction and to determine the relative nucleophilicities of thiols or thiolate anions for addition to an α,β -unsaturated anhydride.

No side reactions occur under preferred preparative conditions. The data obtained indicate that the reaction appears to involve dissociation of the thiol and addition of the thiolate to a polarized double bond. Qualitative experiments demonstrated that the addition of thiol is kinetically controlled and that the rates of thiol additions are proportional to the acid strengths of the thiols. Base strength and steric effects in the amines used influence the rate of the addition reaction as does the nature of the solvent.

Iwakura and Okada³ studied the kinetics of the tertiary amine catalyzed addition of thiols to isocyanates and found the reaction to be first order in each reactant. Clearly their system is similar to ours. The catalytic activity of the bases paralleled that of the pK values except for the unusually active, sterically unhindered triethylenediamine. They were unable to explain their finding that an aromatic thiol adds less readily than an aliphatic thiol. The latter result does not agree with observations made in our previous study. The rate of reaction was found to be generally

dependent upon the dielectric constant of the solvent but no definite relationship was established.

Results

Table I lists data obtained for the addition of 1-butanethiol to maleic anhydride in the presence of triethylenediamine in xylene solution. The second-order nature of the reaction is shown by the calculated rate constants and the satisfactory plot in Fig. 1. The effects of the initial concentrations of reactants on the rate of thiol disappearance are collected in Table II and reveal that the addition is first order in each reactant, but each run is pseudo second order since the concentration of amine remains essentially constant throughout the course of reaction.

TABLE I
SAMPLE DATA FOR THE ADDITION OF 1-BUTANETHIOL TO MALEIC ANHYDRIDE AT EQUAL CONCENTRATION IN THE PRESENCE OF $3.17 \times 10^{-3} M C_6H_{12}N_2$ AT 25°

Time, sec.	$n-C_4H_9SH$, $M \times 10^3$	k , $M^{-1} \text{sec.}^{-1} \times 10^3$	Time, sec.	$n-C_4H_9SH$, $M \times 10^3$	k , $M^{-1} \text{sec.}^{-1} \times 10^3$
0	3.96	..	1920	2.78	5.61
600	3.48	5.68	2010	2.78	5.38
690	3.42	5.68	2700	2.46	5.71
1200	3.27	4.45	2790	2.43	5.71
1290	3.07	5.68			

TABLE II
EFFECTS OF INITIAL CONCENTRATIONS ON THE RATE OF ADDITION

$n-C_4H_9SH$, $M \times 10^3$	$H_2C_4O_3$, $M \times 10^3$	$C_6H_{12}N_2$, $M \times 10^3$	$-d[RSH]/dt$, $M \text{sec.}^{-1} \times 10^5$	k , $M^{-2} \text{sec.}^{-1} \times 10^{-2}$
3.96	3.96	3.17	5.45	1.8
7.92	3.96	3.17	10.2	1.7
3.96	7.92	3.17	11.2	1.7
3.96	3.96	6.34	11.2	1.9

(1) Presented at the 146th National Meeting of the American Chemical Society, Denver, Colo., Jan. 20, 1964.

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