methyl compound, on the other hand, the negative charge is distributed by resonance stabilization. Nucleophiles with dispersed charges, such as carbonate and carboxylates, generally show decreased reactivity.²⁷

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The Reactions of Bromomalononitrile with Bases

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Pentacyanopropenide anion and bromomalononitrile anion are the products of the reaction of ammonia with bromomalononitrile and not aminomalononitrile as reported previously. These products are also obtained when potassium hydroxide, triethylamine, or morpholine is used in place of ammonia. The 1,2-dicyano-1,2dimorpholinoethylene structure previously assigned to a by-product obtained from the reaction of morpholine with bromomalononitrile has been revised to 1,1-dimorpholino-2,2-dicyanoethylene. We believe that tetracyanoethylene is an intermediate in the formation of the pentacyanopropenide ion and of 1,1-dimorpholino-2,2dicyanoethylene.

Recently, it has been suggested that the synthesis of adenine from hydrogen cyanide and aqueous ammonia proceeds via an intermediate, aminomalononitrile, a trimer of HCN.¹ It had been reported independently that aminomalononitrile is formed from bromomalononitrile on treatment with ammonia in methanol at -80° , and that a material similar to hydrogen cyanide polymer is obtained on allowing the solution to warm to room temperature.² We decided to investigate this reaction further, with the hope of elucidating the role of aminomalononitrile in the polymerization of HCN.³

Addition of ammonia to bromomalononitrile in methanol at -80° caused an immediate yellow coloration of the solution, as originally reported.² However, a similar coloration was produced by potassium hydroxide, triethylamine, or morpholine. The solutions all showed similar absorption maxima at 395 and 413 m μ after reaching room temperature. We have succeeded in isolating the pentacyanopropenide anion as its tetraethylammonium and tetramethylammonium salts from each solution. The latter is identical with an authentic sample prepared from tetracyanoethylene, as shown by its melting point, infrared spectrum, and ultraviolet spectrum.⁴

The spectra of all the reaction mixtures include an additional maximum at 235 m μ which does not appear in the spectrum of the pentacyanopropenide anion. We believe it to be due to the bromomalononitrile anion. When bromomalononitrile was added to excess methanolic potassium hydroxide (0.45 N) at room temperature and the spectrum was measured immediately, only a trace amount of the yellow propenide anion was observed and the major ultraviolet-absorbing product was the substance with an ultraviolet peak at 235 m μ (ϵ 15,000 if complete conversion is assumed). On addition of acid this peak disappeared, but could be regenerated by subsequent treatment with alkali. Bromomalononitrile could be recovered unchanged from the acidified solution. We considered the possibility that in alkaline solution the bromomalononitrile decomposed to give positive bromine, e.g., as follows.

$$BrCH(CN)_2 + 2OH^- \longrightarrow -CH(CN)_2 + OBr^- + H_2O$$

However, neither $CH(CN)_2^-$ nor OBr^- absorbs at 235 mµ—the OBr⁻ ion has an absorption maximum at 330 m μ , which we did not observe.⁵

When ammonia was used as the base a shoulder was present in the ultraviolet spectrum of the reaction mixture which suggested the presence of a fourth band at about 255 m μ in addition to the main bands discussed above. If the reaction mixtures were diluted with excess methanol before being brought to room temperature, this shoulder became a well-resolved peak. Attempts to isolate the compound responsible for the 255-mµ peak were abandoned when a mixture containing at least seven new compounds was obtained.

Since the pentacyanopropenide ion is one of the principal products obtained on treating tetracyanoethylene with alkalies,⁴ it seemed at least possible that our reactions were proceeding via tetracyanoethylene. Two further observations are consistent with this mechanism.

When tetracyanoethylene is treated with primary or secondary amines, 1,1-diamino-2,2-dicyanoethylenes are produced.⁶ The product obtained from the reaction of tetracyanoethylene and morpholine was found to be identical with a derivative obtained previously² by treatment of bromomalononitrile with morpholine and formulated as I. Clearly, this substance is in fact II.

When the solution obtained by adding ammonia to bromomalononitrile in methanol at -80° is analyzed for tetracyanoethylene using the color reaction with dimethylaniline,⁶ positive results are obtained. The yield is always small, never exceeding 1.5% in our experience. This is quite consistent with a tetracyano-

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ethylene intermediate, since tetracyanoethylene reacts so readily with bases⁶ that we would not expect it to build up to a high concentration.

We feel that our results are most readily understood if the reaction sequence is as follows.^{6a} If the formation

$$CHBr(CN)_2 + OH^- \longrightarrow -CBr(CN)_2 + H_2O$$

 $CHBr(CN)_2 + -CBr(CN)_2 - -$



of tetracyanoethylene depends on the condensation of an anion with a neutral molecule, the importance of the order of addition on the amount of propenide obtained from bromomalononitrile and alkali is readily understood. If the nitrile is added to alkali it is rapidly and completely converted to an anion, but if the addition is in the opposite order the anion formed has time to react with neutral bromomalononitrile. We are unable to decide whether the further transformation of tetracyanoethylene to pentacyanopropenide proceeds through condensation with bromomalononitrile or by attack on a second tetracyanoethylene molecule. The observation that triethylamine will react with tetracyanoethylene⁷ to form an anion radical which is converted by oxygen to the pentacyanopropenide anion makes the latter pathway quite plausible.

The results described above make it improbable that any considerable amount of aminomalononitrile is produced during the reaction of ammonia with bromomalononitrile. It seems unlikely, therefore, that studies of the reactions of bromomalononitrile with amines have any relevance to the polymerization of HCN.

Experimental⁸

Bromomalononitrile.^{2,9}—Bromine (97 g., 0.60 mole) was added over a period of 1 hr. to 40 g. (0.60 mole) of malononitrile dissolved in 400 ml. of water. A brown oil precipitated from the solution. It was washed with water and then taken up in 100 ml. of chloroform. After drying and concentrating to 50 ml. the solution was cooled overnight in a refrigerator; 17.5 g. (20% yield) of crystals, m.p. 63-64°, deposited.

Reaction of Ammonia with Bromomalononitrile.—A solution of 0.68 g. (0.04 mole) of ammonia in 70 ml. of ethanol was added over a period of 1 hr. to a solution of 2.9 g. (0.02 mole) of bromomalononitrile in 50 ml. of ethanol cooled in Dry Ice-acetone.

(7) O. W. Webster, W. Mahler, and R. E. Benson, ibid., 84, 3678 (1962).

(8) Infrared spectra were measured in potassium bromide on a Perkin-Elmer 237B spectrometer. Ultraviolet spectra were measured on a Cary 14 spectrometer. The analysis is by Midwest Microlab, Indianapolis, Ind. (9) B. C. Hesse, Am. Chem. J., 18, 723 (1896).

The spectrum of a sample of this solution measured at room temperature immediately after dilution with 1000 ml. of methanol exhibited three maxima at 235, 395, and 413 m μ and an inflection at 255 m μ . The optical densities at these wave lengths were 1.73, 0.14, 0.15, and 0.5, respectively. If the solution was held at -80° for 24 hr. and then treated in an identical manner the intensity of the peak at 235 m μ was only 0.92 while the other peaks remained essentially unchanged.

The yield of pentacyanopropenide anion was 0.115 g. (14%) as determined spectroscopically. This ion was also isolated as its tetramethylammonium salt (m.p. $319-320^{\circ}$, lit. m.p. 314°) and its tetraethylammonium salt (m.p. $223-224^{\circ}$, lit. m.p. $220-221^{\circ}$). The infrared and ultraviolet spectra and mixture melting point of the tetramethylammonium salt showed it to be identical with an authentic sample (m.p. $317-320^{\circ}$) prepared from tetracyano-ethylene.⁴

If we suppose that bromomalononitrile is converted completely to its anion in 0.45 N methanolic KOH we can estimate that ϵ_{235} for this ion is about 15,000 (see below). Then our measurements show that immediately after the addition of ammonia our solutions contain about 2.0 g. (69%) of the anion.

To estimate tetracyanoethylene in our reaction mixture a 1ml. sample was added to *ca*. 8 ml. of dimethylaniline and the mixture was allowed to stand overnight at room temperature. Colorimetric analysis indicated the presence of 0.01 g. of tetracyanoethylene in the total reaction mixture.⁶

When 1-ml. samples of the reaction mixture diluted with 1000 ml. of methanol were allowed to stand at room temperature, the inflection at 255 m μ increased to a maximum (optical density 0.96). This peak did not appear when the total reaction mixture was allowed to warm to room temperature without prior dilution.

In a separate experiment the total cooled reaction mixture was poured into 800 ml. of methanol at -80° . The mixture was allowed to warm slowly to room temperature. At the end of 4 hr. the peak at 235 m μ had disappeared and a maximum was observed at 255 m μ . After concentration nearly to dryness with an air aspirator, the residue was taken up in 25 ml. of water and extracted into ether. The ether extract was thoroughly washed with water, dried, and concentrated to yield 0.7 g. of a brown oil. This material exhibited only one ultraviolet maximum in the 210-440-m μ region, at 255 m μ . However, thin layer chromatography (3:1 benzene-methanol on silica gel) revealed the presence of at least seven substances.

We repeated the above experiments under somewhat different conditions. Increasing the amount of ammonia to 0.08 mole did not significantly change the yields of products. If only 0.02 mole of ammonia was added, the yields (determined spectrophotometrically) were 1.06 g. (37%) of bromomalononitrile anion, 0.29 g. (36%) of pentacyanopropenide anion, and 0.02 g. (1.5%) of tetracyanoethylene. Using 0.04 mole of ammonia at room temperature a 61% yield of pentacyanopropenide anion was observed spectrophotometrically and a 53% yield was isolated as the tetraethylammonium salt (m.p. 220-221°).

Reaction of Bromomalonitrile with Potassium Hydroxide.— Bromomalononitrile (5.8 mg.) was dissolved in 100 ml. of methanol and 1 ml. of this solution was diluted to 10 ml. with 0.1 N methanolic potassium hydroxide. The only absorption maximum was at 235 m μ (ϵ 15,000). The intensity of this peak did not change when stronger alkali (0.5 N KOH) was used. The peak disappeared when the solution was acidified and reappeared when it was again made basic. When the same experiment was carried out with malononitrile, no maximum was observed down to 210 m μ .

Bromomalononitrile (2.9 g., 0.02 mole) in 50 ml. of methanol was added to a 50-ml. methanolic solution of 2.24 g. (0.04 mole) of potassium hydroxide cooled to -80° . This solution was acidified with aqueous hydrobromic acid, concentrated, and extracted into ether. Concentration of the ether solution yielded 1.80 g. of bromomalononitrile. In a blank experiment where no base was used 1.94 g. of bromomalononitrile was recovered. The infrared spectra of the two samples were identical. These experiments establish that bromomalononitrile is reversibly transformed to the ultraviolet-absorbing material, and that the reaction is complete in 0.1 N KOH.

The reaction described above was repeated, but using only 0.02 mole of KOH. The bromomalononitrile was added during a 30min. period, and after a further 30 min. the spectrum was measured. The yields of bromomalononitrile anion, pentacyanopropenide anion, and tetracyanoethylene were 1.13 g. (39%), 0.33

⁽⁶a) NOTE ADDED IN PROOF.—In nonpolar solvents tetracyanoethylene may also be formed from dicyanocarsene. See J. S. Sevenson and D. J. Renaud, J. Am. Chem. Soc., 87, 1394 (1965).

Reaction of Bromomalononitrile and Tetracyanoethylene with Triethylamine.—A solution of 1.45 g. (0.01 mole) of bromomalononitrile in 25 ml. of methylene chloride was added over a 15-min. period to a solution of 2.02 g. (0.02 mole) of triethylamine in 25 ml. of methylene chloride at -80° . The absorption spectrum in methylene chloride indicated the presence of 0.21 g. (50%) of the pentacyanopropenide anion [λ_{max} 418 m μ (ϵ 23,450) and 399 m μ (ϵ 23,800) for a methylene chloride solution of pure tetramethylammonium pentacyanopropenide]. When the mixture was allowed to warm to room temperature it turned very dark. The solution absorbed throughout the visible, but the maxima at 399 and 418 m μ were still present. Analysis for tetracyanoethylene indicated the presence of 0.015 g. (2%).

The above reaction was performed using tetracyanoethylene in place of bromomalononitrile.⁷ To a suspension of 0.64 g. (0.05 mole) of tetracyanoethylene in 50 ml. of methylene chloride at -80° was added 0.5 g. (0.05 mole) of triethylamine in 50 ml. of methylene chloride. Addition was completed in 1 hr. The reaction was stirred for 2 hr. and then analyzed spectrophotometrically. The yield of pentacyanoethenolate anion was 0.195 g. (44%). Analysis for tetracyanoethylene indicated the presence of 0.052 g. (8%).

Reaction of Bromomalononitrile with Morpholine.²—To a solution of 2.9 g. (0.02 mole) of bromomalononitrile at -80° was

added 3.48 g. (0.04 mole) of morpholine in 20 ml. of ether. A yellow precipitate formed immediately. After stirring for 7 hr. the solution was filtered and the precipitate was washed with ethanol. The residue left on the filter crystallized from acetonitrile in the form of needles, m.p. 203-208°. This material had an infrared spectrum (KBr) that was identical with that of a sample of morpholine hydrobromide prepared from hydrogen bromide and morpholine (m.p. 208-211°).

The filtrate from the morpholine hydrobromide was added to 0.02 mole of tetraethylammonium bromide to yield 0.48 g. (32%) of tetraethylammonium pentacyanopropenide, m.p. $218-220^{\circ}$.

1,1-Dimorpholino-2,2-dicyanoethylene.⁶—Morpholine (7.0 g., 0.08 mole) was added to 5.0 g. (0.039 mole) of tetracyanoethylene dissolved in 50 ml. of pyridine. The mixture became warm and turned dark orange-brown. It was heated slowly to boiling and then allowed to stand at room temperature for 66 hr. Some product crystallized from the solution. The mixture was poured onto 550 g. of ice, filtered, and washed with water to yield 6.3 g. (65%) of tan crystals, m.p. 277-279°. Recrystallization from acetonitrile yielded white rhombs, m.p. 276-278°. The infrared spectrum of this material was identical with that published for dimorpholinofumaric acid dinitrile, lit.² m.p. 277.5-278.9°.

Anal. Caled. for $C_{12}H_{16}N_4O_2$: C, 58.05; H, 6.50; N, 22.56. Found: C, 58.32; H, 6.84; N, 22.44.

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The Acylation of β-Keto Esters. Control of the Position of Acylation by Variation of the Acylating Agent and Solvent^{1a}

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The amount of C- and O-acylation has been determined when the magnesium chelates of 2-carbethoxycyclopentanone and 2-carbethoxycyclohexanone are allowed to react in tetrahydrofuran with ethyl chloroformate, chloracetyl chloride, acetyl chloride, acetyl bromide, acetyl perchlorate, and propionyl chloride. The first two acid halides give C-acylation. The other acylating agents yield about 80-95% C-acylated product with the exception of acetyl perchlorate which yields only 60-65% C-acylation. Increasing solvent polarity results in decreased C-acylation. A mechanism is proposed which is consistent with these data.

When the metal salts of β -keto esters are allowed to react with acid halides, it is possible to get products resulting from attack at the carbon atom (cf. III) or oxygen atom (cf. V) of the β -keto ester system.² Numerous examples of β -keto ester acylations have been recorded in the literature with varying yields of Cand O-acylated product reported, but very few systematic studies of this reaction have been recorded.³ We have undertaken an investigation of the chemistry of the ambident β -keto esters with the hope of delineating the factors which direct the reaction to carbon or oxygen. The cyclic β -keto esters were chosen for this study since the conformational aspects of these rigid systems are well understood, and these compounds are models of more complicated structures where such information will be of synthetic value (e.g.,alkaloids and steroids).

When ethyl chloroformate was allowed to react with the sodium chelates of cyclic β -keto esters, we observed that steric factors governed the proportion of carbon and oxygen acylation.² A similar steric argument was proposed simultaneously by Rhoads and Decora⁴ to explain that the relative rates of alkylation of the cyclic keto esters are 2-carbethoxycycloheptanone > 2-carbethoxycyclopentanone > 2-carbethoxycyclohexanone. Steric effects have also been suggested by Murdoch and Nonhebel⁵ to explain the relative amounts of C- and O-acylation of β -diketones.⁶

Since the importance of steric effects is well documented, the present study was undertaken with the hope of discovering other factors which determine the proportion of C- or O-acylation. It was also the aim of this study to look for methods which would yield the synthetically more useful C-acylated product; thus the sodium chelates used in the initial study which

^{(1) (}a) Grateful acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for partial support of this research. (b) Inquiries should be directed to J. P. F. at The Salk Institute.

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