

2-amino-5-(2-pyrazinyl)pyrimidine: mp 213–216°; $\lambda_{\text{max}}^{\text{EtOH}}$ 236 m μ (ϵ 5670), 266 (16,300), 295 (20,500); ν^{Nujol} 3100, 3300 (NH), 1660 (C=N) cm $^{-1}$.

Anal. Calcd for C $_8$ H $_7$ N $_5$: C, 55.48; H, 4.07; N, 40.44. Found: C, 55.28; H, 4.35; N, 40.22.

2-(*p*-Chlorophenyl)-5-(2-pyrazinyl)pyrimidine (Vc).—A mixture of 12 g (0.068 mole) of 3-dimethylamino-2-(2-pyrazinyl)acrolein and 11 g (0.0575 mole) of *p*-chlorobenzamidine hydrochloride⁶ in 200 ml of dimethylformamide was refluxed for 2 hr and then allowed to cool overnight. Filtration furnished 9 g (50%) of substantially pure 2-(*p*-chlorophenyl)-5-(2-pyrazinyl)pyrimidine, mp 215–218°. Recrystallization from dimethylformamide gave analytical material: mp 215.5–217.5°, $\lambda_{\text{max}}^{\text{EtOH}}$ 300 m μ (ϵ 36,200).

Anal. Calcd for C $_9$ H $_8$ ClN $_4$: C, 62.58; H, 3.38; Cl, 13.19; N, 20.85. Found: C, 62.77; H, 3.40; Cl, 13.27, 13.39; N, 20.71.

Acknowledgment.—The authors wish to thank Mr. S. Klutchko for many helpful discussions of this work. We are also indebted to Mrs. U. Zeek for the microanalysis and to Mr. R. Puchalski for the spectral data reported herein.

(6) P. A. Fanta and E. A. Hedman, *J. Am. Chem. Soc.*, **78**, 1434 (1956).

Electrolytic Reductive Coupling. XI.¹ Reaction with Acceptors of the Intermediates Produced by Electrolytic Cleavages

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While there is a considerable literature on the electrolytic reductive cleavage of a variety of organic structures (*e.g.*, quaternary ammonium² and phosphonium³ salts, alkyl⁴ and aryl halides, disulfides,⁵ activated carbon–nitrogen and carbon–sulfur⁶ bonds), there seems to have been no attempt to involve the intermediates produced by cleavage in *in situ* reactions with suitable organic acceptors. Previously the fragments have simply been allowed to react with proton donors available in the catholyte and the products obtained or postulated have formally been those that might have been expected from selective hydrogenolysis of the starting materials.⁷

In our continuing study of electrolytic reductive coupling as a synthetic tool we have examined the possibility of effecting condensations by producing by electrolytic fission donors—radicals, anion radicals, carbanions—in the presence of activated olefins (usually acrylonitrile) as acceptors. This principle of condensation was confirmed for two classes of electrolytically generated donors. Yields were poor because of competing reactions which will be discussed below. The following paper⁸ reports a more intensive investiga-

tion of one type of cleavage–condensation reaction, that in which the donors are derived from certain cyanoalkylonium compounds.

Electrolyses at a mercury cathode of compounds LCH $_2$ E⁹ (L = “leaving group” liberated by electroreduction, E = electron-withdrawing group) in aqueous quaternary ammonium electrolytes containing excess acrylonitrile were used as one model system.

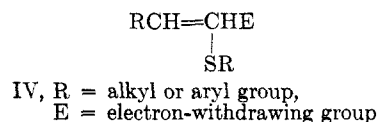
Dimethylcyanomethylsulfonium *p*-toluenesulfonate (I) took up 88% of the theory required for two electrons at a cathode voltage (*see*) which gradually changed from –0.75 to –1.08 v. The only condensation product isolated was glutaronitrile (20% crude,¹⁰ 10% distilled material).

Benzyl dimethylsulfonium *p*-toluenesulfonate (II) underwent a (coulometric) two-electron reduction at a cathode voltage (*see*) of –1.41 to –1.59 v. The crude condensation product (29%) on distillation was found to have 4-phenylbutyronitrile as the major component.

Carbethoxymethyltriphenylphosphonium bromide (III) took up 83% of two electrons at –1.5 to –1.6 v (*see*). Triphenylphosphine, ethyl acetate and 4% of ethyl 4-cyanobutyrate were virtually the only products.

The achievement of satisfactory yields in the above electrolyses in which acrylonitrile is used as an acceptor is hampered by (a) the need for including a proton donor in the catholyte in order to eliminate the possibility of initiating anionic polymerization by (CH $_2$ E) $^-$, (b) the concomitant promotion of the neutralization of (CH $_2$ E) $^-$ to CH $_3$ E, (c) the tendency for the catholyte to become *acidic* (further improving the opportunity for forming CH $_3$ E), because in a two-electron cleavage of LCH $_2$ E one neutral moiety L is released and the resultant carbanion, either directly or after addition to the acceptor, reacts with water to liberate only *one* (OH) $^-$ while simultaneously *two* hydroxide ions are being discharged at the anode. It may be possible to compensate for this effect by adding base slowly to the catholyte (provided the base itself does not by nucleophilic attack cause disruption of LCH $_2$ E) or by using an anhydrous anolyte in which the discharge of an anion, *e.g.*, bromide, would not lead to an accumulation of protons.

An even more complex situation obtains in the electrolysis of IV in the presence of acrylonitrile. The intact molecule IV, being an activated olefin, forms



hydro dimer, dihydro product, and the product of mixed reductive coupling.¹¹ In addition IV undergoes electrolytic fission¹² to yield RCH=CHE and RS $^-$.

(8) Paper XI: M. M. Baizer and J. H. Wagenknecht, *J. Org. Chem.*, in press.

(9) It is necessary to choose models which are reduced at a cathode voltage at least 0.2–0.3 v more positive than the voltage required for reduction of acrylonitrile (–1.9 v vs. *see*) in order to avoid forming the reduction products of the latter.

(10) All yields given are based on current input assuming a two-electron process.

(11) M. M. Baizer, *Tetrahedron Letters*, 973 (1963).

(12) This fission was apparently unrecognized previously and may explain certain polarographic anomalies reported in the literature, *e.g.*, H. E. Simmons, R. D. Vest, D. C. Blomstrom, J. R. Roland, and T. L. Cairns, *J. Am. Chem. Soc.*, **84**, 4752 (1962).

(1) Paper X: M. R. Ort and M. M. Baizer, *J. Org. Chem.*, **31**, 1646 (1966).

(2) S. D. Ross, M. Finkelstein, and R. C. Petersen, *J. Am. Chem. Soc.*, **82**, 1582 (1960).

(3) L. Horner, F. Röttger, and H. Fuchs, *Chem. Ber.*, **96**, 3141 (1963).

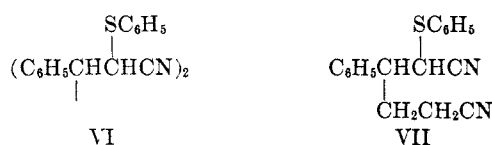
(4) P. J. Elving, I. Rosenthal, J. R. Hayes, and A. J. Martin, *Anal. Chem.*, **33**, 330 (1961).

(5) H. Lund, *Talanta*, **12**, 1065 (1965), and references cited therein.

(6) P. Zuman, O. Manoušek, and V. Horák, *Collection Czech. Chem. Commun.*, **29**, 2906 (1964).

(7) Coupling of radical intermediates has been reported in certain cases.^{2,4}

The mercaptide ion may add to acrylonitrile or to $RCH=CH_2$. In addition, if the latter is reduced at a cathode voltage not much more negative than that required for IV, it would also undergo the electrolytic reactions of activated olefins; e.g., α -phenylthiocinnamionitrile (V) underwent reduction at a (manually) controlled potential of -1.32 to -1.45 v (sce)¹³ using 88% of the current required for two electrons. The products obtained were the hydro dimer VI,¹⁵ the



product of mixed coupling VII,¹⁵ and 3-phenylthiopropionitrile. Electrolysis of V in the absence of acrylonitrile yielded VI, thiophenol, cinnamionitrile,¹⁶ and 3-phenyl-2- (or 1-) phenylthiopropionitrile.

Experimental Section¹⁷

Dimethylcyanomethylsulfonium *p*-Toluenesulfonate (I).—A mixture of 43.5 g (0.5 mole) of methylthioacetone and 93.0 g (0.5 mole) of methyl *p*-toluenesulfonate was kept in a stoppered flask at room temperature. Crystallization began after about 1 week and crops were removed by filtration over the course of 3 months. The crude product (36.8 g, 26.9%) was recrystallized from ethanol, mp 122°.

Anal. Calcd for $\text{C}_{11}\text{H}_{15}\text{NO}_3\text{S}_2$: C, 48.32; H, 5.53; N, 5.12; S, 23.42. Found: C, 48.37; H, 5.74; N, 5.60; S, 23.31.

Attempts to accelerate the formation of I by conducting the reaction in refluxing ethanol led to other products instead.

Benzylmethylsulfonium *p*-Toluenesulfonate (II).—A mixture of 46.2 g (0.334 mole) of benzyl methyl sulfide and 62.2 g (0.334 mole) of methyl *p*-toluenesulfonate was allowed to stand at room temperature. Crystallization began after about 2 hr. The mixture was diluted with dry ether and the first crop (19.3 g) was removed by filtration and washed with ether. The mother liquor was freed of ether and allowed to stand until further crystallization occurred. Repetition of this procedure over a period of 2 weeks yielded a total of 83.1 g (76.6%) of crude product which was recrystallized from ethanol-ethyl acetate, mp 122–123° (lit.¹⁹ mp 124–124.8°).

α -Phenylthiocinnamionitrile (V).—This preparation was based on the synthesis described²⁰ for the α -methylthio analog. Compound V boiled at 165° (0.3 mm) and had n_D^{25} 1.6741.

Anal. Calcd for $\text{C}_{15}\text{H}_{11}\text{NS}$: C, 75.91; H, 4.68; N, 5.90; S, 13.51. Found: C, 75.70; H, 4.79; N, 5.86; S, 13.34.

On standing or trituration with ethanol, V crystallized, mp 57–58° after washing with absolute ethanol.

Electrolysis of I in the Presence of Acrylonitrile.—The catholyte contained 26.2 g (0.096 mole) of I, 25.0 g of tetraethylammonium *p*-toluenesulfonate, 130 ml of acrylonitrile, 3 ml of water, and a trace of *p*-nitrosodimethylaniline as stabilizer. The anolyte was a 50% solution of the quaternary salt. Electrolysis proceeded at 21–25°, a current of 2.0 amp which was gradually reduced, and a cathode voltage of -0.75 to 1.08 v (sce). Triethylamine was added dropwise to the catholyte to maintain slight alkalinity.

(13) If we assume that electron attack is occurring at the β -carbon atom, then the fact that V is reduced at a significantly more positive cathode voltage than is cinnamionitrile (ca. -1.4 to -1.6 v vs. sce) gives indication of the activating influence of the phenylthio group. Previous demonstrations of this effect have been more difficult.¹⁴

(14) G. Cilento, *Chem. Rev.*, **60**, 147 (1960).

(15) The structures are proposed on the basis of the unexceptional β -to- β coupling we have found throughout the work on electrolytic reductive coupling and reported in previous papers in this series.

(16) The isolation of this electroreducible product again illustrates the control achievable by cathode voltage regulation.

(17) Melting points and boiling points are uncorrected. The electrolytic cell and general operating procedures have been described.¹⁸ The cathode was mercury; vpc analyses were done using an F & M Model 300; the preparative vpc was performed on an F & M Model 770.

(18) M. M. Baizer, *J. Electrochem. Soc.*, **111**, 215 (1964).

(19) C. G. Swain and E. R. Thornton, *J. Org. Chem.*, **26**, 4808 (1961).

(20) K. D. Gundermann and R. Huchting, *Chem. Ber.*, **95**, 632 (1962).

The total current was 4.54 amp-hr. The catholyte was transferred to a separatory funnel, the mercury was removed, and the organic layer was diluted with an equal volume of water and extracted with six 50-ml portions of methylene chloride in the presence of hydroquinone. The extracts were washed and then dried over anhydrous magnesium sulfate. Volatile components were removed on the water bath by aspirator. The residue (2.9 g) was distilled collecting only the portion (1.5 ml) boiling at 102–108° (2.2 mm), n_D^{25} 1.4420. Vpc analysis on a silicone nitrile column at 175° showed that the distillate contained 83.5% of glutaronitrile; the retention time was checked on an authentic sample and the identity with the product confirmed by the peak enhancement method.

Electrolysis of II in the Presence of Acrylonitrile.—The catholyte contained 32.4 g (0.1 mole) of II, 30 g of the above electrolyte, 14 ml of triethylamine, 10 ml of water, and 100 ml of stabilized acrylonitrile. The electrolysis was carried out at 0–8° at a cathode voltage of -1.41 to -1.59 v (sce) and a total current of 5.37 amp-hr. Work-up as above yielded 4.2 g of crude product containing 68.7% of 4-phenylbutyronitrile (vpc analysis). The portion collected by distillation at 122–132° (7–8 mm) had n_D^{25} 1.5129 (authentic sample, n_D^{25} 1.5130) and the same retention time as an authentic sample. The identity was further checked by the peak enhancement method.

Electrolysis of III in the Presence of Acrylonitrile.—The catholyte (250 ml) contained 50 g (0.12 mole) of III dissolved in a solution of 50:50 acrylonitrile–80% tetraethylammonium *p*-toluenesulfonate and was made slightly alkaline with dilute sodium hydroxide. The electrolysis occurred at 25–30° and -1.5 to -1.6 v (sce) at 2 to 0.3 amp (total 5.25 amp-hr). Work-up was as above. The materials volatile on the water bath, after fractionation to remove methylene chloride, were found (vpc) to be acrylonitrile and ethyl acetate. From the nonvolatile material there was obtained by distillation at 80° (1.5 mm) about 1 ml of crude ethyl 4-cyanobutyrate. The major component (0.5 ml), n_D^{25} 1.4243, was collected from a preparative vpc column at 200° containing XE-60 silicone gum, 3% on Teflon. The purified sample was identical in n_D and retention time with an authentic specimen. The undistilled residue was digested for several hours with hexane. The hexane solution was decanted, concentrated to a small volume, and extracted with concentrated hydrochloric acid. The acid solution on treatment with sodium hydroxide yielded white crystals of triphenylphosphine, mp 80–81°, after drying at 50°; the mixture melting point with authentic sample was unchanged.

Electrolysis of V in the Presence of Acrylonitrile.—The catholyte contained 23.7 g (0.10 mole) of V, 50 g of methyltriethylammonium *p*-toluenesulfonate, 15 ml of water, and 85 ml of stabilized acrylonitrile. Electrolysis at 20 to 27°, -1.32 to 1.45 v (sce), and 2.0 to 0.3 amp was carried out for 4.71 amp-hr. Precipitation of the hydrodimer VI began after the first hour. After separation of the mercury the catholyte was filtered to remove 3.6 g of VI, mp 270–275°. Recrystallization from dimethylformamide followed by drying at 100° *in vacuo* raised the melting point to 288–289°.

Anal. Calcd for $\text{C}_{30}\text{H}_{24}\text{N}_2\text{S}_2$: C, 75.59; H, 5.07; N, 5.88; S, 13.45. Found: C, 75.35; H, 5.27; N, 6.09; S, 13.42.

The filtered catholyte was diluted with water and extracted with methylene chloride. The extracts were washed with water, dried over anhydrous magnesium sulfate, and filtered. After removal of the volatile components at 100° (aspirator), the residue was fractionated through a 2-ft jacketed Vigreux column: (1) bp 91–113° (1.0 mm), n_D^{25} 1.5906–1.5830, 4.1 g; (2) bp 103–141° (0.35 mm), n_D^{25} 1.5745–1.5756, 2.9 g; (3) bp 145–163° (0.35 mm), 0.8 g, n_D^{25} 1.5851, and (4) 15.4 g of higher boiling residue.

Fraction 2 was redistilled, and the portion boiling at 102–104° (0.45 mm), n_D^{25} 1.5732, was found to be identical with 3-phenylthiopropionitrile [lit.²¹ bp 154° (8 mm), n_D^{25} 1.5735]. Residue 4 was dissolved in methylene chloride and purified by passage through a column of activated alumina. From the effluents, collected in 75-ml portions, there were isolated an additional 1.5 g of VI and ca. 5.5 g of a solid, mp 173–174° (methanol), of empirical formula $\text{C}_{15}\text{H}_{12}\text{N}_2\text{S}$. The noncrystalline residues were combined and distilled. The fraction (5.0 g) boiling at ca. 202–206° (0.4 mm), n_D^{25} 1.5929, showed the correct analysis for VII.

(21) C. D. Hurd and L. L. Gershbein, *J. Am. Chem. Soc.*, **69**, 2328 (1947).

Anal. Calcd for $C_{18}H_{16}N_2S$: C, 73.93; H, 5.52; N, 9.58; S, 10.97. Found: C, 74.18; H, 6.08; N, 9.38; S, 11.10.

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Cyanovinyltetrazoles

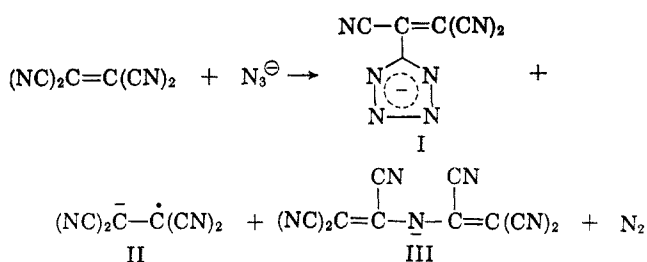
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The preparation of 5-substituted tetrazoles by reaction of inorganic azides with nitriles has been found to proceed most rapidly with negatively substituted nitriles.^{1,2} Norris² has stated that in the case of electro-negatively substituted nitriles the initial step is a nucleophilic addition of azide ion to the nitrile group without aid of a catalyst. Subsequent ring closure of the iminoazide forms the tetrazole ring. With an electro-positively substituted nitrile the initial addition of azide ion requires the assistance of an acid catalyst, *e.g.*, ammonium chloride, and higher temperatures. An extreme example of the former case is the reaction of sodium azide with trifluoroacetonitrile which proceeds exothermically at room temperature in acetonitrile.²

In an investigation of the reaction of inorganic azides with selected cyanoethylenes, particularly tetracyanoethylene (TCNE), it has been found that the reaction proceeds rapidly at temperatures as low as the freezing point of dimethylformamide (-61°) or acetonitrile (-41°). The reaction gives salts of 5-tricyano-



vinyltetrazole (I), tetracyanoethylene anion radical (TCNE \cdot^-)^{3,4} (II), and bistricyanovinylamine⁵ (III), and the yields of these products are markedly temperature and solvent dependent.

Early experiments in acetonitrile at 0° using commercial sodium azide gave erratic results with incomplete utilization of azide ion. Nitrogen was evolved, and gross mixtures of I, II, and III were formed. Subsequent experiments utilized a recrystallized, finely divided form of sodium azide (see the Experimental

Section) which gave rapid reactions at the freezing point of the solvent.

Addition of TCNE to a suspension of sodium azide in acetonitrile at temperatures as low as -25° resulted in a slow evolution of nitrogen (20–25% molar equiv based on azide ion). The ultraviolet absorption spectrum of the crude product indicated the presence of III in molar amount approximately equivalent to that of the evolved nitrogen, and large amounts of an unknown material later shown to be I. The amount of TCNE \cdot^- was so low that it could not be detected satisfactorily by ultraviolet absorption spectroscopy. However, the presence of TCNE \cdot^- was demonstrated by electron paramagnetic resonance studies.³ Thus, the reaction below

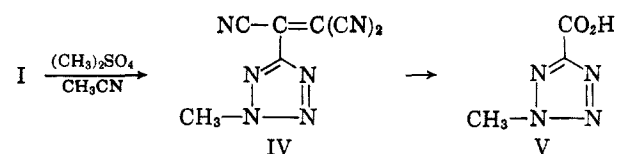


is of minor importance. In other experiments TCNE \cdot^- was found to be inert to azide ion under these conditions. The tetrazole (I) formed a tetramethylammonium salt, but initial attempts to separate it from III by crystallization or chromatography were only partly successful because of its hydrolytic and thermal instability.

The use of dimethylformamide or dimethylacetamide as solvent at -20° resulted in the formation of the tetrazole anion in good yield with little nitrogen evolution. The tetrazole was obtained as the tetramethylammonium salt in 65% yield by rapid recrystallization from acetonitrile-ether. The infrared and ultraviolet spectra of this salt, as well as a structural degradation, are in complete accord with proposed structure I. The infrared spectrum gives no evidence for the presence of a free azide group and shows strong absorption at 4.52 (conjugated $\text{C}\equiv\text{N}$) and 6.35μ ($\text{N}=\text{N}$ or $\text{C}=\text{N}$). The ultraviolet spectrum in acetonitrile has λ_{max} 360 $m\mu$ (ϵ_{max} 10,800) and 237 $m\mu$ (ϵ_{max} 3640). A freshly prepared aqueous solution has λ_{max} 327 $m\mu$, but the solution does not obey Beer's law because of reaction with the solvent.

The formation of tetrazole I may be accounted for by the mechanism proposed by previous authors,^{1,2} and the extreme ease of reaction of azides with an electro-negatively substituted nitrile is in accord with their data.

The structure of I was rigorously established by the following reaction sequence; I, as a tetramethyl-



ammonium salt, was methylated at 25° by excess methyl sulfate in acetonitrile. A single product was isolated to which was assigned structure IV; *i.e.*, methylation occurred in the 2 position. This is in accord with the observation of Henry and Finnegan⁶ that alkylation of tetrazole salts having electronegative substituents at the 5 position gives predominantly the 2-substituted product while those with electropositive groups in the 5 position give predominantly the 1-substituted compound. The validity of this structural assignment was shown by degradation of IV to the known 2-methyl-

(1) W. G. Finnegan, R. A. Henry, and R. Lofquist, *J. Am. Chem. Soc.*, **80**, 3908 (1958).

(2) W. P. Norris, *J. Org. Chem.*, **27**, 3248 (1962).

(3) W. D. Phillips, J. C. Rowell, and S. I. Weissman, *J. Chem. Phys.*, **33**, 626 (1960).

(4) O. W. Webster, W. Mahler, and R. E. Benson, *J. Am. Chem. Soc.*, **84**, 3678 (1962).

(5) W. J. Middleton, E. L. Little, D. D. Coffman, and V. A. Engelhardt, *ibid.*, **80**, 2794 (1958).

(6) R. A. Henry and W. G. Finnegan, *ibid.*, **76**, 923 (1954).