216. D. Jerchel and W. Melloh, Annalen, 613, 144 (1958).
217. E. Ochiai and M. Ikehara, J. Pharm. Soc. Japan, 71, 1385 (1951); Chem. Abs., 46, 7101 (1952).
218. D. Jerchel and W. Jacobs, Angew. Chem., 66, 298 (1954).
219. J. Francis, J. K. Landquist, A. A. Levi, J. A. Silk, and J. M. Thorp, Biochem. J., 63, 455 (1956).
220. M. Eckstein, M. Gorczycowa, and A. Kocwa, Roczniki Chem., 31, 847 (1957).
221. S. J. Childress and J. V. Scudi, J. Org. Chem., 23, 67 (1958).
222. A. Risaliti and R. Lolli, Farmaco Ed. Scient., 12, 705 (1957); Ref. Zhur. Khim., 46 817 (1958).
223. G. B. Brown, H. A. Stevens, and H. W. Smith, J. Biol. Chem., 233, 1509 (1958).
224. M. A. Stevens, H. W. Smith, and G. B. Brown, J. Amer. Chem. Soc., 81, 1734 (1959).
225. H. Krause and W. Langenbeck, Chem. Ber., 92, 155 (1959).
226. W. Nakahara and F. Fukucka, J. Cancer Res., 48, 129 (1957).
227. H. Euler and H. Hasselquist, Arkiv Kemi, 12, 553 (1958).

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CYANOETHYLATION, DECYANOETHYLATION, and TRANSCYANOETHYLATION

P. F. Butskus

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INTRODUCTION

The β-cyanoethyl group $-CH_2CH_2CN$ is most frequently introduced into compounds containing a mobile hydrogen atom by reacting them with acrylonitrile. The cyanoethylation with acrylonitrile has in the last 15–20 years been widely studied on many organic compounds. Alcohols, phenols, mercapto compounds, oximes, amides, aliphatic and aromatic amines, heterocyclic bases, phosphines, arsines, and compounds in which a mobile hydrogen atom is linked to carbon (certain hydrocarbons, polyhalogeno-alkanes, nitro-compounds, aldehydes, ketones, acid derivatives, compounds of the acetoacetic and malonic ester type, and sulphones) have all been cyanoethylated. Several hundreds of original publications and patents and several reviews have dealt with this subject[1-3]. Cyanoethylation is a very simple and convenient method for the preparation of a large number of compounds otherwise difficult to obtain, which are indispensable for the development of various fields of chemical industry.

Cyanoethylation with acrylonitrile proceeds according to the following scheme:

$$R{-}H + CH_2{=}CHCN \rightarrow R{-}CH_2CH_2CN.$$

Cyanoethylation is reversible. Hence by introducing a new compound capable of cyanoethylation into a system in equilibrium transcyanoethylation products can be obtained:

$$R{-}CH_2CH_2CN \underset{+R{-}H}{\overset{-R{-}H}{\rightleftharpoons}} CH_2{=}CHCN \underset{-R'{-}H}{\overset{+R'{-}H}{\rightleftharpoons}} R'{-}CH_2CH_2CN$$

In certain cases decyanoethylation occurs, when acrylonitrile is eliminated (sometimes as a polymer or as acrylic acid):

$$R{-}CH_2CH_2CN \rightarrow R{-}H + CH_2{=}CHCN.$$

Cyanoethylation and its reverse are base catalysed[4].

This review covers all the methods of cyanoethylation with reagents other than acrylonitrile, as well as decyanoethylation and transcyanoethylation. This last reaction can hardly be discussed separately, since it consists in simultaneous cyanoethylation and decyanoethylation:

$$R{-}CH_2CH_2CN + R'{-}H \rightarrow R'{-}CH_2CH_2CN + R{-}H.$$

In addition to acrylonitrile, β-halopropionitriles, ethylene cyanohydrins, β-alkoxypropionitriles, cyanoethyl esters, β-aminopropionitrile and its *N*-substituted derivatives, and certain other compounds can also be used as cyanoethylating agents. In cases where cyanoethylation with acrylonitrile yields polymers, by using some of the above agents the reaction can be carried out under milder conditions and arrested at the monomer stage. These agents are also known to give positive results in cases where acrylonitrile failed to react or gave too low yields of the product. Certain cyanoethyl compounds can only be obtained by transcyanoethylation.

The course of decyanoethylation and transcyanoethylation provides the evidence that the bond attaching β-cyanoethyl groups to oxygen, sulphur, nitrogen, carbon, *etc.*, is, as a rule, more labile than the bonds between alkyl radicals or other groups with these atoms. The mobility of the β-cyanoethyl group is clearly demonstrated by the decyanoethylation of certain cyanoethyl derivatives on distillation.

Decyanoethylation and transcyanoethylation are interesting both from the theoretical and preparative viewpoints. For instance, β-cyanoethyl group can be used for protecting an amino-group[5,6]:

$$R{-}NH_2 + CH_2{=}CHCN \rightarrow RNH{-}CH_2CH_2CN \rightarrow$$

$$\xrightarrow{\text{alkylation}} \begin{matrix} R' \\ R \end{matrix}\!\!>\!N{-}CH_2CH_2CN \xrightarrow{\text{heating}} \begin{matrix} R' \\ R \end{matrix}\!\!>\!NH + CH_2{=}CHCN.$$

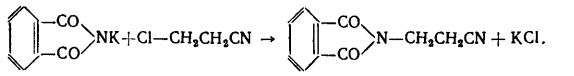
1. β-HALOPROPIONITRILES AS CYANOETHYLATING AGENTS

(a) Cyanoethylation with β-chloropropionitrile. The β-halopropionitrile most widely used in cyanoethylations is β-chloropropionitrile.

The reaction of β-chloropropionitrile with acid sodium sulphide[7], sodium sulphide[8], potassium sulphide[9], ammonium thiocyanate[10], sodioacetoacetic ester[11] and potassium phthalimide[12] yields cyanoethylation products. For example:

$$K_2S + 2\ Cl{-}CH_2CH_2CN \rightarrow S(CH_2CH_2CN)_2 + 2\ KCl,$$

$$NH_4SCN + Cl{-}CH_2CH_2CN \rightarrow NCS{-}CH_2CH_2CN + NH_4Cl,$$



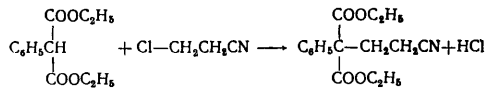
β-Chloropropionitrile has been used for the cyanoethylation of ethanol[13].

The reduction of β-chloropropionitrile by Vyshnegradskii's method yields γ-alkoxypropylamines[14]:

$$Cl{-}CH_2CH_2CN \xrightarrow[KOH]{Na} RO{-}CH_2CH_2CH_2NH_2.$$

The reaction of β-chloropropionitrile with ketones[15,16] can be more easily stopped at the stage of monocyanoethylation, and the yields of products are, as a rule, higher than in the case of acrylonitrile.

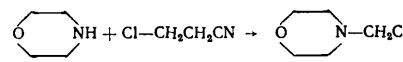
Phenylmalonyl diethyl ester reacts with β-chloropropionitrile forming 32% cyanoethylation product[17]:



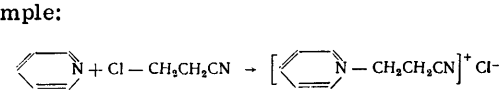
Heininger[10,18] showed that in the reaction of β-chloropropionitrile with amines, different products are obtained depending on the nature of the amine. Certain amines (trimethylamine, triethylamine, quinoline, quinaldine, α-picoline, acridine, *etc.*) react with β-chloropropionitrile forming amine hydrochlorides and acrylonitrile, for instance:

$$(CH_3)_3N + Cl{-}CH_2CH_2CN \rightarrow (CH_3)_3N{\cdot}HCl + CH_2{=}CHCN.$$

On the other hand amines like n-butylamine, pyrrolidine, and morpholine yield in this case the hydrochlorides of *N*-substituted β-aminopropionitriles:



Still another group of amines (pyridine, isoquinoline, β- and γ-picolines) form the quaternary ammonium salts, for example:



According to Heininger[18] the reaction of β-chloropropionitrile with aniline in absolute ethanol yields aniline hydrochloride and acrylonitrile. Butkus and Denis[19] showed, however, that in aqueous solution these two compounds react forming *N*-(β-cyanoethyl) aniline in good yield:

$$C_6H_5NH_2 + Cl{-}CH_2CH_2CN \rightarrow C_6H_5NH{-}CH_2CH_2CN + HCl.$$

The cyanoethylation of α-amino-acids with β-chloropropionitrile[20,21] is accompanied by heat evolution and proceeds according to the following scheme:



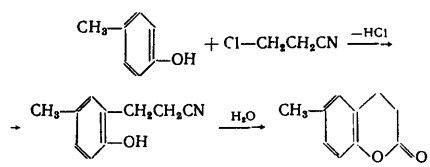
Cyanoethylation of glycine, alanine, α-aminobutyric acid, cystine, β-phenyl-α-alanine, and tyrosine, in 70–96% yields, has also been reported.

β-Chloropropionitrile was also used to obtain the *N*-cyanoethylation products of β-phenyl-β-alanine[22], γ-aminobutyric acid, δ-aminovaleric acid, ε-aminohexanoic acid, and taurine[23].

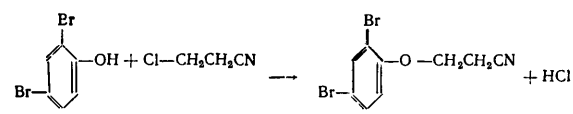
Tsukervanik and Grebenyuk[24–26] showed that direct cyanoethylation of benzene and chlorobenzene with acrylonitrile by the Friedel–Craft–Gustavson method proceeded with difficulty and gave low yields. This reaction proceeds more readily and with better yields if hydrogen chloride is added to acrylonitrile. In that case, presumably, it is not acrylonitrile, but β-chloropropionitrile which takes part in the reaction. The reaction proceeds equally readily with β-chloropropionitrile:

$$C_6H_6 + Cl{-}CH_2CH_2CN \xrightarrow{AlCl_3} C_6H_5{-}CH_2CH_2CN + HCl.$$

Probably the nuclear cyanoethylation of phenols by acrylonitrile and hydrogen chloride in the presence of zinc or aluminium chloride also proceeds via an intermediate formation of β-chloropropionitrile[27–34]. Cyanoethylation of the nucleus in the presence of the Friedel–Crafts–Gustavson catalyst proceeds only with great difficulty. β-Chloropropionitrile, on the other hand, may be used to obtain the products of cyanoethylation in the nucleus of many mono- and polyhydric phenols[32–34], for example:



If phenols are treated with β-chloropropionitrile in the presence of caustic alkali, cyanoethylation takes place at the hydroxyl group[35], as for example:



β-Chloropropionitrile has also been used to cyanoethylate ammonia[18,36–38], diethylamine[39], glycylglycine[21], hexitylamines[40], anthranilic acids[41,42], piperidine[43], 1-benzyl-5-aminotetrazole[44], peptones and proteins[23], cellulose[45] and other compounds[6,39,46–52].

In certain cases the cyanoethylation seems to proceed not by the direct substitution of the halogen but via the formation of acrylonitrile as an intermediate[15,41]. This assumption is favoured by the fact that acrylonitrile is formed from β-chloropropionitrile by the action of potash, caustic alkali or tertiary amines, *i.e.* compounds which react with hydrogen chloride[18,20,21,41,53]. This reaction may be of preparative importance, since the yield of acrylonitrile may reach 75–80%. Other cases of the formation of acrylonitrile from β-chloropropionitrile have also been reported[54].

(b) Use of other β-halopropionitriles in cyanoethylation. β-Bromopropionitrile was used for the cyanoethylation of diethylamine, aniline, piperidine, glycine, α-alanine, α-aminobutyric acid, cystine, α-aminophenylacetic acid, tyrosine, β-phenyl-α-alanine, β-phenyl-β-alanine, taurine, δ-aminovaleric acid, ε-aminohexanoic acid[55], hexitylamines[40], 5-aminotetrazole, 1-benzyl-5-aminotetrazole[44], certain compounds containing a mobile

hydrogen atom attached to carbon[56,57], and other compounds[58,59]. Caustic alkali and tertiary amines react with β-bromopropionitrile forming acrylonitrile[55].

β-Iodopropionitrile has also been used in cyanoethylation[46].

There are no data in the literature on the use of β--fluoropropionitrile for this purpose.

2. INTRODUCTION OF THE CYANOETHYL GROUP BY MEANS OF ETHYLENE CYANOHYDRIN

The reaction of ethylene cyanohydrin with aqueous solution of potassium cyanide results in low yields of succinic dinitrile[60].

In the course of the reduction of ethylene cyanohydrin with sodium in a series of alcohols, *e.g.* ethyl, isopropyl, n-butyl, and isopentyl, the alcohol undergoes cyanoethylation, which is followed by the reduction of the nitrile group[14]:

$$HO{-}CH_2CH_2CN \xrightarrow[ROH]{Na} RO{-}CH_2CH_2CH_2NH_2.$$

In no case was it possible to isolate γ-propanolamine from the reaction mixture.

Ethylene cyanohydrin reacts with benzyl alcohol in the presence of sodium forming β-benzyloxypropionitrile[61]:

$$C_6H_5CH_2OH + HO{-}CH_2CH_2CN \rightarrow C_6H_5CH_2O{-}CH_2CH_2CN + H_2O.$$

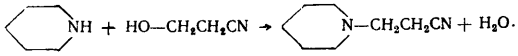
The reaction of ethylene cyanohydrin with triphenylchloromethane in the presence of pyridine yields β-(triphenylmethoxy)propionitrile[62]:

$$(C_6H_5)_3CCl + HO{-}CH_2CH_2CN \rightarrow (C_6H_5)_3CO{-}CH_2CH_2CN + HCl.$$

Heated with ammonia, ethylene cyanohydrin forms β-alanine[63]. When a mixture of an amine with ethylene cyanohydrin at 300° is passed over finely powdered aluminium good yields of *N*-substituted β-aminopropionitriles are obtained[64].

In the reaction with aniline ethylene cyanohydrin yields only traces of β-(phenylamino)propionitrile[19].

The cyanoethylation of piperidine with ethylene cyanohydrin yields β-(*N*-piperidyl)propionitrile[65,66]:



The yield of the product is 22%. If powdered tin is added to the reaction mixture, as in the preparation of acrylonitrile, the cyanoethyl derivatives of piperidine is obtained in 52.5% yield.

In the presence of tin powder at 150°–170°, anabasine and ethylene cyanohydrin form the corresponding *N*-cyanoethyl derivative in 60% yield[67].

Chelintsev and his associates[68-70] showed that ethylene cyanohydrin reacted with esters of carboxylic acids in the presence of equimolar amount of sodium alcoholate forming β-alkoxypropionitriles:

$$HCOOC_2H_5 + HO{-}CH_2CH_2CN + C_2H_5ONa \rightarrow HCOONa + C_2H_5O{-}CH_2CH_2CN + C_2H_5OH.$$

The authors regard this reaction as an unusual alkylation of ethylene cyanohydrin by carboxylic esters.

The reaction of ethylene cyanohydrin with acids, acid anhydrides and acid chlorides, as well as with isocyanates, yields the cyanoethyl esters of the corresponding acids[1,3,71-84].

In the reaction with phosphorus trichloride, ethylene cyanohydrin yields β-cyanoethyldichlorophosphite in addition to β-chloropropionitrile[85]:

$$PCl_3 + HO{-}CH_2CH_2CN \begin{cases} \nearrow Cl{-}CH_2CH_2CN \\ \searrow Cl_2{\cdot}PO{-}CH_2CH_2CN \end{cases}$$

There are data on the use of ethylene cyanohydrin in cyanoethylations of hexitylamines[40], aldehydes and ketones[86], resorcinol (in the nucleus)[32], phenylhydrazine[52], indole[87], and other compounds[33,88,89]. Attempts to cyanoethylate α-amino-acids[20,90] and proteins[23] with ethylene cyanohydrin were unsuccessful, although under the same conditions these substances reacted with acylonitrile and β-halopropionitriles.

Ethylene cyanohydrin react with certain ethers, replacing an alkyl group by cyanoethyl group[91,92], for example:

$$(CH_3)_2CHOCH{=}CH_2 + HO{-}CH_2CH_2CN \rightarrow CH_2{=}CHO{-}CH_2CH_2CN + (CH_3)_2CHOH.$$

The reaction can proceed similarly with esters[93].

3. MOBILITY OF THE CYANOETHYL GROUP BOUND TO OXYGEN

(a) β-Alkoxypropionitriles. The existence of a dynamic equilibrium and the reversibility of cyanoethylation is especially noticeable in the reaction of acrylonitrile with alcohols. Only the β-alkoxypropionitriles obtained by cyanoethylating lower primary or secondary alcohols (up to C_7) can be isolated from the reaction mixture by simple distillation. On further increase of the molecular weight, the boiling point of the resulting β-alkoxypropionitrile is so high that on distillation the reverse reaction can occur[1,94,95]. Yields obtained in cyanoethylations of secondary alcohols are lower than those from primary alcohols. The reaction of tertiary alcohols with acrylonitrile is even more difficult. Certain tertiary alcohols, *e.g.* t-butanol, can be used as solvents in cyanoethylations. On heating to 60°–80° t-butanol reacts with acrylonitrile, but the resulting ether readily decomposes into the starting components[1-3].

An exchange of the alkyl radicals takes place on heating (50°–60°) β-alkoxypropionitriles with aliphatic or aliphatic-aromatic alcohols in the presence of alkali or alcoholates[61,96]:

$$RO{-}CH_2CH_2CN + R'{-}OH \rightleftarrows R'O{-}CH_2CH_2CN + ROH.$$

The yield of transcyanoethylation products is 75–80%.

Kost and Yashunskii[14] observed that if in the Vyshnegradskii reduction the alkoxy groups in β-alkoxypropionitrile and in the alcohol used as solvent are identical, the normal reaction product is obtained, the amine corresponding to the nitrile taking part in the reaction (*e.g.* β--ethoxypropionitrile in ethanol yields γ-ethoxypropylamine). If they are not identical, the γ-alkoxypropylamine formed contains the alkoxy group from the alcohol used as solvent. For instance, the reductions of both β-methoxypropionitrile and β-(β′-hydroxyethoxy)propionitrile in n-butanol yield only γ-butoxypropylamine. Similar observations were made by Seeger[97].

It may be noted that in the Vyshnegradskii reaction α- and γ-alkoxynitriles undergo normal reduction, without the exchange of alkoxy groups.

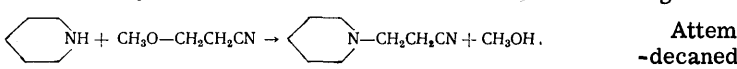
The cleavage of the cyanoethyl–oxygen bond occurs in the reduction of β-alkoxypropionitriles with lithium aluminium hydride[98,99], or with Raney nickel catalyst [100–102]. The yields of alcohols in reductions by lithium aluminium hydride are 80–90%.

Attempts to hydrate the β-cyanoethyl ether derived from dimethyl vinyl ethynyl carbinol in aqueous methanol solution resulted in the splitting off of one molecule of acrylonitrile, followed by the isomerisation of the remaining dimethyl vinyl ethynyl carbinol into β,β-dimethyldivinyl ketone; under the reaction conditions used the latter compound united with methanol forming 1-methoxy-5-methyl-4--hexen-3-ol[103]. The saponification of β-cyanoethyl ethers to the corresponding acids has to be carried out with concentrated hydrochloric acid, since heating with alkalis catalyses the reversal of cyanoethylation. The alkaline hydrolysis of β-cyanoethyl ethers derived from acetylenic alcohols in 50% aqueous methanol yields β-methoxypropionic acid[106]. Heating β-alkoxypropionitriles with aqueous ammonia yields β-alanine[107,108].

Decyanoethylation occurs on pyrolysis of β-alkoxypropionitriles[109]. Heating β-methoxypropionitrile at 300°–350° yields 80–90% acrylonitrile. Acrylonitrile is obtained in the same yield from β-ethoxypropionitrile. Other cases of the cleavage of the bond between the cyanoethyl group and oxygen in acid[109,110] or alkaline media[1-3,14,95,110] are also known.

Certain β-alkoxypropionitriles can be used as cyanoethylating agents. For instance, β-methoxypropionitrile was used to cyanoethylate ammonia[107,111], dimethylamine[112], dibutylamine[112,113], piperidine[113], morpholine and other amines[112]. In all cases the products of transcyanoethylation were isolated, namely β-aminopropionitrile and its *N*-substituted derivatives:

$$(CH_3)_2NH + CH_3O{-}CH_2CH_2CN \rightarrow (CH_3)_2N{-}CH_2CH_2CN + CH_3OH,$$



In the reaction with β-ethoxypropionitrile, malonic ester gave its mono- and di-cyanoethyl derivatives[113]. This alkoxynitrile was used in the preparation of *N*-(β--cyanoethyl)indole[87]. Cyanoethylation of diethylamine and malonic ester was also carried out by means of β-butoxypropionitrile[114].

Heating β-alkoxypropionitriles with aromatic amines[19,115] in aqueous solution at 100° results in transcyanoethylation according to the following scheme:

$$C_6H_5NH_2 + RO{-}CH_2CH_2CN \rightarrow C_6H_5NH{-}CH_2CH_2CN + ROH.$$

Alkoxypropionitriles were obtained by cyanoethylating methyl, ethyl, propyl, butyl, isobutyl, s-butyl, pentyl, and isopentyl alcohols. The reaction proceeds in the presence of very small amounts of caustic alkali or triethylamine.

Instead of acrylonitrile, certain β-alkoxypropionitriles were reacted with phenylhydrazine to form 3-amino-1--phenylpyrazoline[52].

(b) β,β′-Dicyanodiethyl ether. Kost and Yashunskii[14] showed that the Vyshnegradskii reduction of β,β′-dicyanodiethyl ether proceeded in an anomalous manner, giving rise to γ-alkoxypropylamines, in which the alkoxy radical was that of the alcohol used as solvent:

$$O(CH_2CH_2CN)_2 \xrightarrow[C_4H_9OH]{Na} C_4H_9O{-}CH_2CH_2CH_2NH_2.$$

The linear diamine could not be isolated.

Reduction of β,β′-dicyanodiethyl ether in the presence of Raney nickel (15–150 atm, 80°–125°) yielded a mixture of products, from which γ,γ′-diaminodipropyl ether, γ-aminopropanol, and propylamine were isolated[116]:

$$O(CH_2CH_2CN)_2 \rightarrow \begin{cases} O(CH_2CH_2CH_2NH_2)_2 \\ HOCH_2CH_2CH_2NH_2 + CH_3CH_2CH_2NH_2 \end{cases}$$

Use of β,β′-dicyanodiethyl ether for cyanoethylating hydrogen sulphide[117], mercaptans and thiophenols[118], and ketones[119], has been described in patents.

Heating β,β′-dicyanodiethyl ether with aqueous aniline in the presence of small amounts of caustic alkali or triethylamine gave the transcyanoethylation product, *viz.* β-(phenylamino) propionitrile[19].

Heating β,β′-dicyanodiethyl ether at 195°–210° in the presence of sodium formate resulted in 94% acrylonitrile[120]. Acrylonitrile utilised in the side-reaction for the formation of β,β′-dicyanodiethyl ether during the cyanoethylation of cellulose fibres, can in this way be recovered[121]. Decyanoethylation occurs upon saponification[122] and pyrolysis[109] of β,β′-dicyanodiethyl ether, or upon its heating with aqueous ammonia[108].

(c) Products of the cyanoethylation of monohydric alcohols and carbohydrates. Dicyanoethyl derivatives of ethylene glycol and propane--1,2-diol and the tricyanoethyl derivative of glycerol react in aqueous solution at 100° with aromatic amines forming β-arylaminopropionitriles[115]. In contrast to β-alkoxypropionitriles, the glycol di-β-cyanoethyl ether does not require an alkaline catalyst.

Heating diethylene glycol with its dicyanoethyl derivative in the presence of caustic alkali yields the corresponding monocyanoethyl derivative[123].

Attempts to cyclise the dicyanoethyl derivative of 1,10--decanediol by the Ziegler method into the corresponding imine were unsuccessful. In this reaction decanediol was recovered in 90% yield[124]:

$$NCCH_2CH_2{-}O(CH_2)_{10}O{-}CH_2CH_2CN \rightarrow HO(CH_2)_{10}OH + 2\ CH_2{=}CHCN.$$

Yashunskaya *et al.*[125] made a study of the conditions for the preparation of carboxyethylcellulose *via* the cyanoethylation with acrylonitrile. They established that the rate of cyanoethylation increased with increasing concentration of sodium hydroxide up to 8%. Further increase of alkali concentration caused a lowering of the number of cyanoethyl groups in the reaction product. Other conditions being equal, raising the reaction temperature to 45° causes a considerable drop in the extent of cyanoethylation. However, the authors explain this by the concentration of acrylonitrile being reduced due to hydrolysis. On treatment with a solution of caustic soda, or on repeated washing with soap or soda solution, the nitrogen content of the cyanoethyl derivative is lowered[121]. This was also considered to be due to the saponification of cyanoethyl groups. The authors neglected the possible reverse reaction in the presence of alkali, namely of the removal of acrylonitrile from the cyanoethyl derivative of cellulose, or of acrylic acid from its carboxyethyl derivative. Such cleavage of the bond between the cyanoethyl group and oxygen is known to take place in the products of cyanoethylation of polyvinyl alcohol[126,127] and certain polysaccharides[128]. Further evidence was provided by the work of Danilov and Lopatenok[129], who showed that with sodium

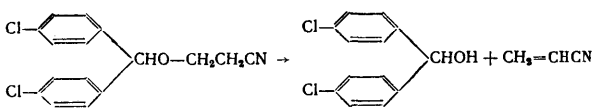
in liquid ammonia cyanoethylcellulose underwent partial deoxidation, the principal reaction under these conditions being the direct removal of acrylonitrile. Polyacrylonitrile and acrylic acid were also observed among the reaction products. No carboxyethylcellulose was observed under these conditions.

(d) Products of the cyanoethylation of alicyclic, aromatic, and heterocyclic alcohols. Boiling β-cyclohexyloxypropionitrile, 1--phenyl-, 2-phenyl-2-propyl-, and 2-phenyl-2-benzyl-1--(β-cyanoethoxy)cyclohexane with chloroacetyl chloride in chloroform or ether, or with bromopropionyl bromide in the presence of potash, results in the formation of the corresponding cyclohexylchloroacetates or cyclohexylbromopropionates[130].

The reaction of β-cyclohexyloxypropionitrile with aniline consists in transcyanoethylation, the product being β--(phenylamino)propionitrile[115].

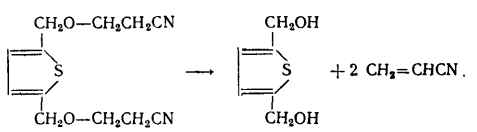
The reaction product from benzaldehyde and acrylonitrile eliminates acrylonitrile in alkaline media[131].

97% decyanoethylation occurs on hydrolysis of the cyanoethyl derivative of *p,p'*-dichlorodiphenylcarbinol with 15–25% alkali solution[132]:



The bond between the cyanoethyl group and oxygen in β-benzyloxypropionitrile undergoes cleavage in the presence of Raney nickel catalyst[100].

Decyanoethylation is also observed during the reduction of the cyanoethyl derivatives of certain heterocyclic alcohols in the presence of Raney cobalt[133]:

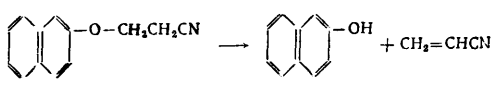


(e) β-Aryloxypropionitriles. The reaction of β-aryloxypropionitriles with aromatic amines in aqueous solution at 100° consists of transcyanoethylation[19,115]:

$$ArO{-}CH_2CH_2CN + Ar'NH_2 \rightarrow Ar'NH{-}CH_2CH_2CN + ArOH.$$

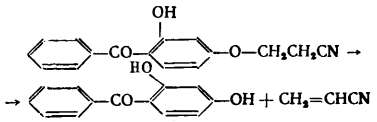
This reaction proceeds more readily than in the case of β-alkoxypropionitriles, and no alkali is required. In addition to the product of transcyanoethylation, that of decyanoethylation could often be isolated. It may be noted that under similar conditions the reaction of aromatic amines with β-aryloxypropionic acids did not form the products of dealkylation or transalkylation.

Decyanoethylation occurs on heating β-phenoxypropionitrile, the β-cyanoethyl ethers derived from α- and β--naphthols, as well as the dicyanoethyl ethers derived from pyrocatechol, resorcinol, and hydroquinone, with 5% alkali solution[115]. Decyanoethylation yields the corresponding phenols, for instance:



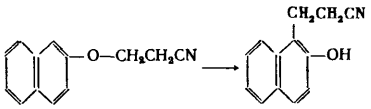
The yield of β-naphthol is 87%.

Certain β-cyanoethyl ethers derived from 2- and 4--aroylphenols behave similarly[134]. For instance, 4-benzoylresorcinol monocyanoethyl ether forms 2,4-dihydroxybenzophenone on heating for five minutes with 10% sodium hydroxide:

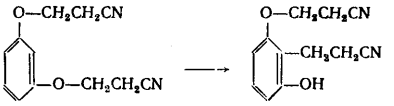


It follows from the foregoing that the β-cyanoethyl ethers derived from phenols cannot be saponified to corresponding β-carboxyethyl ethers using alkali. Mineral acids should be used instead. If the cyanoethyl group is not attached to oxygen, but to carbon [*e.g.* in 1-(β-cyanoethyl)-2-naphthol] the saponification proceeds readily in the presence of alkali hydroxides. In that case neither the higher concentration of alkaline solutions nor longer heating can give rise to decyanoethylation[135].

On heating 2-naphthyl β-cyanoethyl ether in benzene solution in the presence of alkali, the cyanoethyl group is transferred from oxygen to carbon, 1-(β-cyanoethyl)-2--naphthol being formed in the process[115]:



Similar reaction takes place on heating a methanol solution of resorcinol dicyanoethyl ether in the presence of sodium alcoholate:

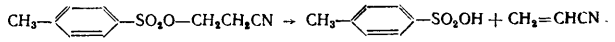


Possibly, the reported *C*-cyanoethylation of 2,6-di-t--butylphenol[136], β-naphthol[135], 9-fluorenol[137], and resorcinol[138] with acrylonitrile in the presence of alkali also proceeds via *O*-cyanoethylation.

The cleavage of the bond between the cyanoethyl group and oxygen is also observed on reduction of β-aryloxypropionitriles with lithium aluminium hydroxide[98] or on pyrolysis[109].

(f) β-Cyanoethyl esters. The preparation of acrylonitrile from ethylene cyanohydrin is sometimes effected by the esterification of the latter compound with acid anhydrides or chlorides followed by thermal or catalytic removal of acrylonitrile[1,78–84], for instance:

$$CH_3COO{-}CH_2CH_2CN \rightarrow CH_3COOH + CH_2{=}CHCN,$$



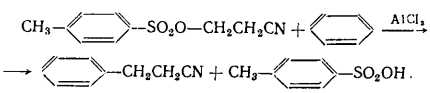
A nitrile group in the β-position to a $-OPO_3H_2$ group acts as an activator of the hydrolysis of these phosphate monoesters. If these two groups are separated by more than two carbon atoms, the activating effect is lost. The effect of the nitrile group in activating hydrolysis is stronger than that of a carboxyl or ester group[139,140]. The β-cyanoethyl group in mixed esters of phosphoric acid is more readily removed by hydrolysis than other groups[141].

Tributylphosphate, dibutyl β-cyanoethyl phosphite, and butyl di-(β-cyanoethyl) phosphite were isolated from the

mixture of products obtained in the reaction of β-cyanoethyl dichlorophosphite with butanol[142]:

$$Cl_2PO{-}CH_2CH_2CN + C_4H_9OH \begin{matrix} \nearrow P(OC_4H_9)_3 \\ \searrow C_4H_9OP(O{-}CH_2CH_2CN)_2 \end{matrix} \longrightarrow (C_4H_9O)_2PO{-}CH_2CH_2CN$$

The reaction of p-toluenesulphonyl cyanoethyl ester with benzene in the presence of aluminium chloride gave 72% β-phenylpropionitrile[78]:



With pyrrolepotassium this ester yields *N*-(β-cyanoethyl)-pyrrole[143].

Cyanoethyl esters have also been used for cyanoethylating piperidine[144] and resorcinol (in the nucleus)[33].

4. THE BOND BETWEEN A CYANOETHYL GROUP AND SULPHUR

Decyanoethylation is observed during the reaction of β-alkylmercaptopropionitriles with organomagnesium compounds[145].

Transcyanoethylation occurs in the reaction of β-cyanodiethyl sulphide with aniline[19] in aqueous solution at 100°:

$$C_2H_5S{-}CH_2CH_2CN + C_6H_5NH_2 \rightarrow C_6H_5NH{-}CH_2CH_2CN + C_2H_5SH.$$

The yield of β-(phenylamino)propionitrile is very small. Certain *S*-cyanoethyl compounds react with heterocyclic bases forming quaternary ammonium salts[10].

The reduction of dicyanodiethyl sulphide by the Vyshnegradskii method yields β-alkoxypropylamines[14]:

$$S(CH_2CH_2CN)_2 \xrightarrow[C_4H_9OH]{Na} C_4H_9O{-}CH_2CH_2CH_2NH_2.$$

This reaction seems to proceed through the intermediate formation of acrylonitrile. An attempt to obtain the linear diamine was unsuccessful. Under these conditions other *S*-cyanoethyl compounds also fail to give the normal reduction products[146].

In 1956, in their study of the action of acrylonitrile on the aqueous solution of sodium sulphinates, Achmatowicz and Michalski[147] showed that an equilibrium was established in the system, containing only small amounts of sulphones. To obtain the latter compounds they added reagents which bind sodium hydroxide. The resulting sulphones (where the cyanoethyl group was one of the radicals) are unstable in alkaline solution, and decomposes even at room temperature yielding acrylonitrile.

$$RS(=O)_2{-}CH_2CH_2CN \rightarrow RSO_2H + CH_2{=}CHCN.$$

5. THE BOND BETWEEN A CYANOETHYL GROUP AND NITROGEN

(a) Cyanoethylation products from ammonia and hydrazine. Terent'ev *et al.*[148] studied the reaction of acrylonitrile with aqueous ammonia: the proportion of the resulting mono-, di-, and tri-cyanoethyl derivatives depends on the reaction conditions and the ratio of the starting components. At all stages of the reaction there existed a dynamic equilibrium between the participants:

$$CH_2{=}CHCN \underset{-NH_3}{\overset{+NH_3}{\rightleftharpoons}} NH_2{-}CH_2CH_2CN \underset{+NH_3}{\overset{-NH_3}{\rightleftharpoons}} NH(CH_2CH_2CN)_2 \underset{+NH_3}{\overset{-NH_3}{\rightleftharpoons}} N(CH_2CH_2CN)_3.$$

Other research workers have also observed the dynamic equilibrium in the cyanoethylation of ammonia[3,58,65,116,149-152]. Using only a small excess of ammonia the main reaction product is β,β′-dicyanodiethylamine (88%). Increased ammonia concentration causes an increase of the yield of β-aminopropionitrile. Raising the reaction temperature also has a favourable effect on the formation of the monocyanoethyl derivative. If the reaction is carried out rapidly (1–5 min), at high temperature (105°–110°), and using considerable excess of ammonia, the yield of β-aminopropionitrile may reach 80–92%.

Moist β-aminopropionitrile decomposes on storage, and pressure builds up in the container even at room temperature[153].

Whitmore and his collaborators considered that the polymer formed during the storage of β-aminopropionitrile consisted of polyacrylonitrile, formed as a result of the liberation of ammonia[58]. Other authors, however, refuted this assumption[148,151].

On catalytic reduction of β-aminopropionitrile, trimethylenediamine, di-(γ-aminopropyl)amine, and tri-(γ-aminopropyl)amine are obtained[58,116]. The same mixture was obtained by the reduction of β,β′-dicyanodiethylamine.

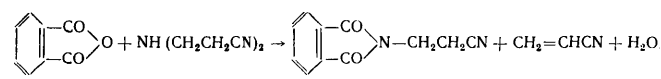
During the storage of pure β,β′-dicyanodiethylamine, ammonia is liberated, leaving the crystalline tricyanoethyl product. If the sample is kept in a closed container, part of the liberated ammonia re-enters the reaction, and β-aminopropionitrile separates on distillation.

Heated to 200°–250° or higher, β,β′-dicyanodiethylamine decomposes into acrylonitrile and β-aminopropionitrile[3,148,154]:

$$NH(CH_2CH_2CN)_2 \rightarrow NH_2{-}CH_2CH_2CN + CH_2{=}CHCN.$$

This reaction proceeds more readily *in vacuo* in the presence of a catalyst, *e.g.* disodium phosphate. The yield of β-aminopropionitrile in that case may reach 85%. Ammonia reacts with β,β′-dicyanodiethylamine forming β-aminopropionitrile[148,149] or β-alanine[155].

β,β′-Dicyanodiethylamine reacts with acetic anhydride and phthalic anhydride forming, respectively, *N*-(β-cyanoethyl)acetamide[150] and the cyanoethyl derivative of phthalimide (at 200°, by elimination of acrylonitrile)[156]:



Heating β,β′-dicyanodiethylamine at 230° with the anhydride of perylene-3, 4, 9, 10-tetracarboxylic acid, yields the dicyanoethyl derivative of the corresponding diimide[157,158].

Efforts to synthesise β,β′dicyanodiethyl(triphenylmethyl)amine from β,β′-dicyanodiethylamine and triphenylchloromethane failed owing to the elimination of one molecule of acrylonitrile during the reaction[62]:

$$(C_6H_5)_3CCl + NH(CH_2CH_2CN)_2 \rightarrow (C_6H_5)_3CNH{-}CH_2CH_2CN + CH_2{=}CHCN + HCl.$$

β-Cyanoethyl(triphenylmethyl)amine was obtained in 78% yield.

In the presence of equimolar amounts of hydrochloric acid, the mono-, di-, and tri-cyanoethyl derivatives of ammonia react with aniline in aqueous solution yielding β-(phenylamine)propionitrile [19].

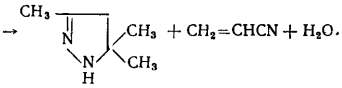
Hydrazine hydrate reacts vigorously with acrylonitrile, adding up to four molecules of the latter. However, the tetracyanoethyl derivative of hydrazine loses two molecules of acrylonitrile on distillation in a high vacuum giving a mixture of the isomeric dicyanodiethyl derivatives of hydrazine [3].

Benzoyl chloride reacts with unsymmetrical di-(β--cyanoethyl)hydrazine forming β-cyanoethyldibenzoylhydrazine [159]:

$$NH_2N(CH_2CH_2CN)_2 + 2\ C_6H_5COCl \rightarrow C_6H_5CONHN\langle^{CH_2CH_2CN}_{COC_6H_5} + CH_2{=}CHCN + 2HCl.$$

Kost and his associates [160] found that heating β-cyanoethylhydrazine with mesityl oxide in neutral solution yields 3, 5, 5-trimethylpyrazoline:

$$NH_2NH{-}CH_2CH_2CN + (CH_3)_2C{=}CHCOCH_3 \rightarrow$$



$$+ CH_2{=}CHCN + H_2O.$$

N-(β-Cyanoethyl)pyrazoline could not be obtained under these conditions. The authors consider that the reaction proceeds by the intermediate removal of β-cyanoethylhydrazine, forming unsubstituted hydrazine. The assumption that the *N*-(β-cyanoethyl)pyrazoline already formed splits off the cyanoethyl group is not probable, since this compound is stable under the given condition.

(b) β-Alkylaminopropionitriles. The instability of the bond between the cyanoethyl group and nitrogen is illustrated by the decyanoethylation of certain β-alkylaminopropionitriles on distillation. Thus, the addition products from acrylonitrile and ethanolamine or diethanolamine decompose completely on vacuum distillation into the starting components [58,161]. The vacuum distillation of higher β-dialkylaminopropionitriles has to be carried out rapidly and at the lowest possible residual pressure, in order to avoid an appreciable dissociation into starting compounds [58].

On heating for many hours at 250°–275° the cyanoethyl derivative of methyldodecylamine decomposes practically quantitatively into the initial amine and acrylonitrile [5,6]:

$$CH_3(CH_2)_{11}\underset{\displaystyle CH_3}{\underset{|}{N}}{-}CH_2CH_2CN \rightarrow CH_3(CH_2)_{11}NHCH_3 + CH_2{=}CHCN.$$

β-(Cyanoethyl)methyldodecylamine is usually obtained by cyanoethylation of dodecylamine followed by methylation. The foregoing reaction thus represents a method for preparing unsymmetrical secondary amines, the cyanoethyl group serving to protect the amino radical.

On heating dicyanoethylethylenedinitramine with aqueous alkali the starting nitramine is recovered in 82% yield [162]:

$$NCCH_2CH_2\rangle^{O_2N}N{-}CH_2CH_2{-}N\langle^{NO_2}_{CH_2CH_2CN} \rightarrow O_2NNHCH_2CH_2NHNO_2 + 2\ CH_2{=}CHCN$$

Decyanoethylation is also observed during the heating of certain β-alkylaminopropionitriles in the presence of water [163], during their saponification in acid media [164], and in some other cases [165].

Heating β-cyanoethyl(triphenylmethyl)amine with an excess of ethylene glycol at 160° –170° for 4–5 hours yields the decyanoethylated product [166]:

$$(C_6H_5)_3CNH{-}CH_2CH_2CN \rightarrow (C_6H_5)_3CNH_2 + CH_2{=}CHCN.$$

The yield of triphenylethylamine is 90%. Decyanoethylation does not proceed with the same ease in the case of β-(dimethylamino) and β-(diethylamino)propionitriles.

β-(Diethylamino)propionitrile hydrochloride decomposes on heating into diethylamine hydrochloride and acrylonitrile [167,168].

Acrylonitrile is readily removed by pyrolysis of the quaternary ammonium salts prepared from β-dialkylaminopropionitriles [53]. In the presence of alkali this proceeds even at 100°, and the yield of acrylonitrile may reach 88%.

During the alkylation of the cyanoethyl derivative of 2--amino-2-methyl-1-propanol with ethyl iodide, acrylonitrile is split off and the hydroiodide of the *N*-ethylated amino alcohol is obtained [169]:

$$HOCH_2C(CH_3)_2NH - CH_2CH_2CN + C_2H_5I \rightarrow HOCH_2C(CH_3)_2NHC_2H_5 \cdot HI + CH_2{=}CHCN.$$

Allyl bromide reacts similarly.

Methylation of β-(benzylamino)propionitrile by formaldehyde and formic acid yields 38% benzyldimethylamine [170]:

$$C_6H_5CH_2NH{-}CH_2CH_2CN + 2\ CH_2O + 2\ HCOOH \rightarrow$$
$$\rightarrow C_6H_5CH_2N(CH_3)_2 + CH_2{=}CHCN + 2\ CO_2 + 2\ H_2O.$$

A great deal of work has been devoted to the study of β-aminopropionitriles as cyanoethylating agents. By heating β-dimethylaminopropionitrile with piperidine at 150°–160° for 10 h, Terent'ev *et al.* [113] succeeded in obtaining 30% β-(*N*-piperidyl) propionitrile:

$$(CH_3)_2N{-}CH_2CH_2CN + \langle\rangle NH \rightarrow \langle\rangle N{-}CH_2CH_2CN + (CH_3)_2NH.$$

They carried out the cyanoethylation of dibutylamine in the same manner.

By heating methanol and butanol with the quaternary methosulphate of β-(dimethylamino)propionitrile, the above authors obtained β-methoxypropionitrile and β-butoxypropionitrile, respectively. For example:

$$(CH_3)_3N{-}CH_2CH_2CN\cdot(CH_3)SO_4^- + CH_3OH \rightarrow CH_3O{-}CH_2CH_2CN + (CH_3)_3N + CH_3HSO_4.$$

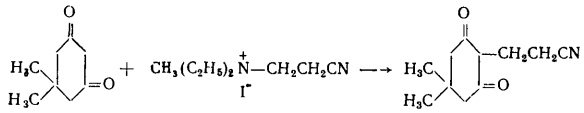
Heated with indole in alkaline solution, β-(dimethylamino)propionitrile forms β-(*N*-indolyl)propionic acid [87].

Methyl and butyl alcohols react with the quaternary salts derived from β-dialkylaminopropionitriles yielding the corresponding β-alkoxypropionitriles [53]. β-Butoxypropionitrile was obtained in 74% yield.

β-(Diethylamino)propionitrile and β-(ethylbenzylamino)-propionitrile methiodides react with potassium cyanide forming succinic dinitrile [60]. β-(Diethylamino)propionitrile methiodide reacts with the aqueous solution of potassium cyanide forming succinic acid [53]. β-(Diethylamino)propionitrile methiodide has also been used for the cyanoethylation of morpholine and malonic ester [114].

Bradford and his collaborators [171] failed in their attempt to cyanoethylate dimedone with acrylonitrile. They succeeded, however, in cyanoethylating the sodium salt of

dimedone with β-(diethylamino)propionitrile methiodide:



Nazarov and Zav'yalov[172] showed later that in the presence of aqueous caustic soda at 100° dimedone reacts readily and completely with acrylonitrile forming mono- and di-cyanoethyl derivatives. These authors dispute the reaction mechanism suggested by English research workers, whereby the possible intermediate formation of acrylonitrile is excluded.

Heated with triethylphosphite, β-(dimethylamino)propionitrile methiodide forms the diethyl ester of β-cyanoethylphosphinic acid[173].

In the reaction of acrylonitrile with 9,10-dihydrophenanthridine Bates and Cymerman-Craig[174] observed that the latter compound underwent dehydrogenation. The cyanoethyl derivative of 9,10-dehydrophenanthridine was obtained using β-(diethylamino)propionitrile.

By heating β-(diethylamino)propionitrile with the salts of aromatic amines, Bekhli[167,168] obtained the monocyanoethyl derivatives of the latter compounds, and thus discovered a new method for the preparation of β-arylaminopropionitriles. The author regards this reaction as one of alkyl–aryl transamination. β-(Diethylamino)propionitrile reacts similarly with anthranilic acids[41].

Cyanoethylation of aromatic amines with β-(diethylamino)propionitrile has also been studied by a number of other research workers[19,60,175-177].

Besides β-(diethylamino)propionitrile, the monocyanoethyl derivatives of methylamine, dimethylamine, butylamine, benzylamine[19] and ethylbenzylamine[60], and the dicyanoethyl derivatives of methylamine, ethylamine, and butylamine, have also been used for cyanoethylating aromatic amines[19].

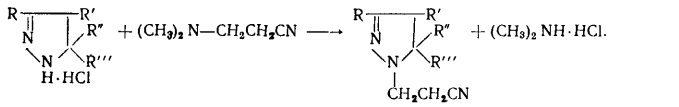
Since it requires only one mole of acid, cyanoethylation is usually carried out with the salts of aromatic amines (hydrochlorides, acetates, sulphonates, *etc.*), or the salts of β-alkylaminopropionitriles. If two moles of acid are present, as for instance in the reaction of the hydrochloride of an aromatic amine with β-alkylaminopropionitrile hydrochloride, transcyanoethylation does not take place. The yield of β-arylpropionitrile increases with the basicity of the aromatic amine. The presence of *O*- or *N*-substituents in aromatic amine has an adverse effect on the yield of cyanoethylation products. The presence of a methyl radical in the cyanoethyl group lowers the capacity of this compound to take part in such reactions. β-(Diethylamino)-α-dimethylpropionitrile (where elimination of the unsaturated compound is not possible) does not react with *p*-anisidine. Nevertheless, the problem of the reaction mechanism remains uncertain.

Bekhli[167,168] considers that the cyanoethylation of aromatic amines by β-(diethylamino)propionitrile proceeds *via* the formation of acrylonitrile, followed by the addition of the latter to the amine. The experimentally established elimination of acrylonitrile in 47% yield under the conditions used in this reaction, and in 77% yield on heating β-(diethylamino)propionitrile hydrochloride in the absence of arylamine, may be taken as evidence supporting this mechanism.

According to Cymerman-Craig and his associates[177] this reaction proceeds by a substitution mechanism. They showed that in the cyanoethylation of arylamine salts by the deuterated diethylaminopropionitrile, $(C_2H_5)_2N-CH_2CHDCN$, the $-CH_2CHDCN$ group remains unchanged throughout the reaction.

A method has been described for the cyanoethylation of aromatic amines[178,179] (in the form of hydrochlorides or benzenesulphonates) and of anthranilic acid[41], by means of acrylonitrile and diethylamine. It is possible that here the reaction proceeds through the intermediate formation of diethylaminopropionitrile, namely that it is in fact a trans-cyanoethylation.

The cyanoethyl derivatives of dimethylamine and diethylamine rather than acrylonitrile itself were reacted with phenylhydrazine in the synthesis of 3-amino-1-phenylpyrazoline[52]. β-(Dimethylamino)propionitrile and *p*-tolylhydrazine similarly gave 3-amino-1-*p*-tolylpyrazoline[180]. The reaction of acrylonitrile with pyrazolines in anhydrous media results not in cyanoethylation, but in a vigorous polymerisation of acrylonitrile. The cyanoethylation of pyrazolines was carried out with β-(dimethylamino)propionitrile[181]:



The reaction proceeds at 170° in the presence of one equivalent of hydrogen chloride (either pyrazoline hydrochloride or aminonitrile hydrochloride are used). The yields of the cyanoethylated pyrazolines are 30–50%.

(c) *N*-Cyanoethyl derivatives of acid amides. On vacuum distillation (150°, 1.9 mm) the dicyanoethyl derivative of acrylamide yields the monocyanoethyl derivative[182]:

$$CH_2=CHCON(CH_2CH_2CN)_2 \rightarrow CH_2=CHCONH-CH_2CH_2CN + CH_2=CHCN.$$

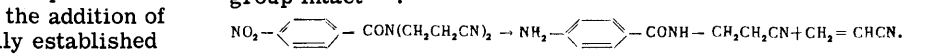
On heating the dicyanoethyl derivatives of a series of amides of carboxylic and sulphonic acids (acetamide, benzamide, *p*-nitrobenzamide, *p*-chlorobenzenesulphonamide, *etc.*) in absolute ethanol, or benzene in the presence of sodium alcoholate or potassium hydroxide for 2–5 h, the *N*-monocyanoethyl derivatives of the corresponding acid amides are formed in good yields[183]:

$$RCON(CH_2CH_2CN)_2 \rightarrow RCONH-CH_2CH_2CN + CH_2=CHCN,$$
$$RSO_2N(CH_2CH_2CN)_2 \rightarrow RSO_2NH-CH_2CH_2CN + CH_2=CHCN.$$

β-Ethoxypropionitrile may be found among the reaction products. In the presence of even very small amounts of water the nitrile group is partly hydrolysed[183,184].

The elimination of one cyanoethyl group is observed on heating certain dicyanoethyl derivatives of thiourea in the presence of alkoxides[185].

One cyanoethyl group is also eliminated during the reduction of the nitro-group in *N*,*N*-di-(β-cyanoethyl)-*p*-nitrobenzamide, under the conditions leaving the nitrile group intact[183]:

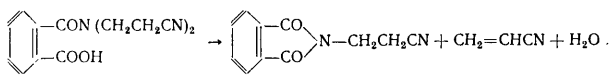


When acetamide is heated with its dicyanoethyl derivative in the presence of alkali the monocyanoethyl derivative is obtained in 62% yield[3]:

$$CH_3CON(CH_2CH_2CN)_2 + CH_3CONH_2 \rightarrow 2\ CH_3CONH-CH_2CH_2CN.$$

p-Toluenesulphonamide and its dicyanoethyl derivative similarly form the monocyanoethyl compound[186]. In fact, the disproportionation of dicyanoethyl compounds in the presence of alkali is the best method for preparing the monocyanoethyl derivatives of arylsulphonamides[187].

Heating dicyanoethyl monoamides of dibasic acids yields the corresponding *N*-cyanoethyl imides[156,188], for instance:



Alkaline hydrolysis of *N*,*N*-dicyanoethyl derivatives of a series of sulphonamides (toluene sulphonamide, *p*-chlorobenzenesulphonamide, β-naphthalenesulphonamide, *etc.*) yields the corresponding carboxylethyl derivatives[184,189-191]:

$$RSO_2N(CH_2CH_2CN)_2 \rightarrow RSO_2NH{-}CH_2CH_2COOH.$$

The hydrolysis of *N*,*N*-dicyanoethyl sulphonamides into dicarboxyethyl sulphonamides is carried out in the presence of hydrochloric acid[192] or a concentrated solution of potassium hydroxide in isopentyl alcohol[187].

(d) Cyanoethylation of amino-acids and their derivatives. The mobility of β-cyanoethyl group in mono- and di-cyanoethyl amino-acids and their derivatives has lately been given much attention. Butskus and Denis[193] established that one of the two cyanoethyl groups attached to nitrogen in amino-acids is easily removed on heating in water in the presence of tertiary amines or caustic alkali:

$$\begin{matrix} R \\ | \\ HOCOCHN(CH_2CH_2CN)_2 \end{matrix} \rightarrow \begin{matrix} R \\ | \\ HOCOCHNH{-}CH_2CH_2CN \end{matrix} + CH_2{=}CHCN.$$

In certain cases this reaction proceeds on simply heating the aqueous solution, or by pyrolysis.

On heating α-amino-acids with their dicyanoethyl derivatives in the presence of caustic alkali, a redistribution of cyanoethyl groups takes place:

$$\begin{matrix} R \\ | \\ HOCOCHN(CH_2CH_2CN)_2 \end{matrix} + \begin{matrix} R \\ | \\ HOCOCHNH_2 \end{matrix} \rightarrow 2\ \begin{matrix} R \\ | \\ HOCOCHNH{-}CH_2CH_2CN. \end{matrix}$$

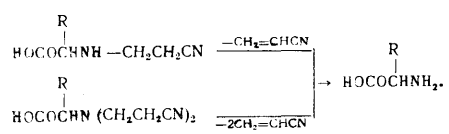
In their study of the *N*,*N*-dicyanoethyl derivatives of α-amino-acids, McKinney and his collaborators[194-196] observed the instability of one cyanoethyl group to heat, alkali, and acids. On heating *N*,*N*-di-(β-cyanoethyl)-α--alanine above its melting point, it solidifies and then melts again at the melting point of *N*-monocyanoethyl-α-alanine.

During the hydrolysis of dicyanoethyl derivatives of α-amino-acids one cyanoethyl group is eliminated giving rise to the formation of monocarboxyethyl derivatives of amino-acids:

$$\begin{matrix} R \\ | \\ HOCOCHN(CH_2CH_2CN)_2 \end{matrix} \rightarrow \begin{matrix} R \\ | \\ HOCOCHNH{-}CH_2CH_2COOH. \end{matrix}$$

There is no formation of dicarboxyethyl derivatives in this reaction.

By selecting suitable reaction conditions, complete removal of cyanoethyl groups in mono- and di-cyanoethyl derivatives of α-amino-acids can be effected[193]:



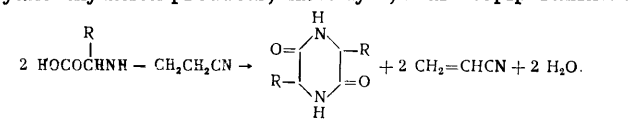
The yields of the products of complete decyanoethylation may reach 80%. The compound to undergo decyanoethylation is heated at 100° in aqueous solution of ammonia, hydrazine, dimethylamine, diethylamine, or piperidine. Other amines, *e.g.* methylamine, ethylene diamine, *etc.* can also be used. Good results are obtained using 2–10% aqueous ammonia. By increasing the ammonia concentration to 25% the yield of the decyanoethylation product is lowered. Use of gaseous or alcoholic ammonia does not give positive results.

The decyanoethylation of esters, amides, or hydrazides of cyanoethyl derivatives of α-amino-acids by 10% aqueous ammonia is accompanied by hydrolysis of the ester, amide, and hydrazide function to carboxylic acid[193,197]. It is remarkable that the presence of water favours both the introduction of cyanoethyl groups into the esters of α-amino-acids[198], and their removal[20,193].

N-Mono- and *N*,*N*-di-(β-cyanoethyl)glycylglycine readily undergo decyanoethylation in the presence of 2–5% aqueous ammonia, namely under the conditions which do not affect the peptide bond[193]. It is thus possible to use the β-cyanoethyl group for the protection of the amino-group in the synthesis of peptides.

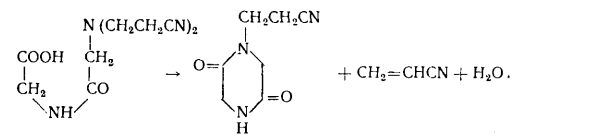
Heating mono- and di-cyanoethyl derivatives of β-amino acids[22], ε-aminohexanoic acid, and taurine[23] with an aqueous solution of ammonia and hydrazine, results in the formation of the corresponding unsubstituted amino-acids. This reaction proceeds less readily with the cyanoethyl derivatives of δ-aminovaleric acid.

On heating α-amino-acids in glycol solution diketopiperazines are formed. Butskus[199] showed, however, that on heating the monocyanoethyl derivatives of α-amino-acids (glycine, alanine, α-aminobutyric acid and valine) in ethylene glycol at 160°–170° the expected 1,4-di-(β-cyanoethyl)-2,5-diketopiperazines are not formed, but their decyanoethylation products, namely 2,5-diketopiperazines:



Dicyanoethyl derivatives of α-amino-acids behave likewise.

Heating *N*,*N*-di-(β-cyanoethyl)glycylglycine in ethylene glycol removes one cyanoethyl group and causes simultaneous cyclisation into 1-(β-cyanoethyl)-2,5-diketopiperazine:



1-(β-Cyanoethyl)-2,5-diketopiperazine is obtained by cyclisation of *N*-(β-cyanoethyl)glycylglycine, *viz.* the reaction proceeds without the elimination of the cyanoethyl group.

The conversion of the cyanoethyl derivatives of α-amino--acids to 2,5-diketopiperazines seems, therefore, to proceed *via* decyanoethylation, followed by the cyclisation of the resulting α-amino-acids. The fact that the reaction can be stopped at a stage where compounds present give a positive ninhydrin reaction, contain an amino-group which may be determined by the Van Slyke method, and give a negative picric acid reaction, may be taken as evidence in

favour of this mechanism[199]. Besides, heating the cyanoethyl derivatives of amino-acids incapable of forming cyclic derivatives (α-aminophenylacetic acid, phenylalanine, and tyrosine) in glycol yields entirely the decyanoethylation products[166]. On the other hand 1,4-di-(β-cyanoethyl)-2,5-diketopiperazine remains unchanged under the above reaction conditions[199].

Mono- and di-cyanoethyl derivatives of taurine also undergo decyanoethylation on being heated in ethylene glycol[166]. Decyanoethylation is observed on heating *N*-(β-cyanoethyl)tyrosine in 1,2-propanediol, glycerol, and erythritol[166], as well as on pyrolysis of *N*-(β-cyanoethyl)-glycylglycine[200]. The products of the decomposition of *N*-(β-cyanoethyl)alanylglycine in the presence of alkali seem to contain the decyanoethylated derivatives[201].

Butskus and others[23,197,202,203] studied the reaction of cyanoethyl products from amino-acids and their derivatives, with aromatic amines. Amines such as aniline, *p*-nitroaniline, *p*-toluidine, and β-naphthylamine react with mono- and di-cyanoethyl derivatives of α-, β, γ-, δ-, and ε-amino-acids forming their decyanoethylated products, namely α-, β-, γ-, δ-, and ε-amino-acids, as well as the corresponding products of transcyanoethylation, *viz.* β-arylaminopropionitriles. This reaction, studied in a number of cases, proceeds according to the following scheme:

$$HOCO(CH_2)_x NH{-}CH_2CH_2CN + ArNH_2 \rightarrow HOCO(CH_2)_x NH_2 + ArNH{-}CH_2CH_2CN,$$
$$HOCO(CH_2)_x N(CH_2CH_2CN)_2 + 2\ ArNH_2 \rightarrow HOCO(CH_2)_x NH_2 + 2\ ArNH{-}CH_2CH_2CN.$$

The yields of amino-acids range from 36 to 92%. The reaction of aromatic amines with the cyanoethyl derivatives of taurine, glycylglycine and alanylglycine proceeds likewise. In the reaction of aromatic amines with the esters, amides, and hydrazides of the cyanoethyl amino-acids hydrolysis of the ester, amide, or hydrazide function to carboxylic group occurs simultaneously with transcyanoethylation.

The cyanoethyl derivatives of proteins and peptides react with aromatic amines forming β-arylaminopropionitriles[23].

All the above reactions are carried out by heating aqueous solution at 100°. Heated at 130°–140° with aromatic amines without the solvent the dicyanoethyl derivatives of α-amino-acids split off one cyanoethyl group forming the monocyanoethyl derivatives. At higher temperatures (180°) the second cyanoethyl group is also eliminated. Nevertheless, in this case the reaction proceeds less readily than in water solution, and there is considerable resinification.

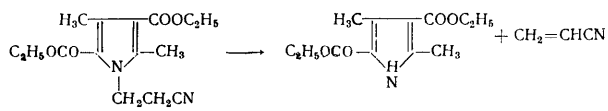
When heated under the above conditions in aqueous ammonia or aniline, or in glycol solution *N*-(β-cyanoethyl)-aceturic acid, *N*-(β-cyanoethyl)hippuric acid and *N*,*N'*-di-(β-cyanoethyl)-2,5-diketopiperazine do not undergo decyanoethylation. This is evidence that the bond of the cyanoethyl group with an amide nitrogen atom is stronger than that with an amine nitrogen.

If heated for many hours with aromatic amines either without a catalyst or in the presence of acids or alkalis, the *N*-carboxyethyl derivatives of α-amino-acids also fail to undergo dealkylation or transalkylation.

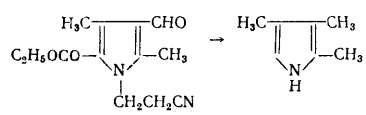
(e) β-(Cyclohexylamine)propionitrile. The cleavage of the bond between the cyanoethyl group and nitrogen in β-(cyclohexylamino)propionitrile has been reported[165,204].

(f) β-Arylaminopropionitriles. The bond between the cyanoethyl group and nitrogen is stronger in β-arylaminopropionitriles than in β-alkylaminopropionitriles. β-Arylaminopropionitriles and *N*-(β-cyanoethyl)-anthranilic acid do not undergo decyanoethylation on being heated in ethylene glycol[166]. Some authors[205], however, report that the removal of the cyanoethyl group from dicyanoethyl derivatives of aromatic amines may occur during their cyclisation. Bekhli[206] pointed out that in acid or alkaline media β-arylaminopropionitriles undergo not only saponification, but also decompose forming an arylamine. This process is minimised by lowering the reaction temperature. Products of the decomposition in acid media of β-(methylphenylamino)propionitrile[207], β-(ethylphenylamino)propionitrile[208], and *N*-(β-cyanoethyl)-anthranilic acid[41,209] also contain decyanoethylated derivatives.

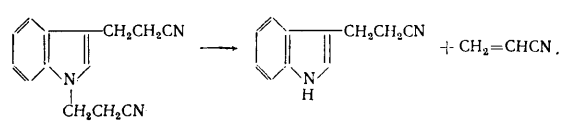
(g) Cyanoethylation of heterocyclic compounds containing nitrogen in the nucleus. Certain derivatives of *N*-(β-cyanoethyl)pyrrole lose a cyanoethyl group on being heated at 150° with sodium ethoxide in absolute ethanol, forming the corresponding pyrroles[210]. For example:



In the reduction of β-(2,4-dimethyl-3-formyl-5-ethoxycarbonylpyrryl-1)propionitrile by the Kishner method, 2,3,4-trimethylpyrrole is obtained:



The *N*,β-dicyanoethyl derivative of indole splits off acrylonitrile on heating *in vacuo* to 250°, forming quantitatively β-cyanoethylindole, which is stable under these conditions[87]:

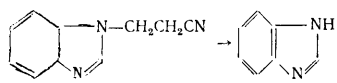


Heated with concentrated potassium hydroxide *N*-(β-cyanoethyl)indole undergoes hydrolysis to the corresponding acid, and yields at the same time indole (10%), the product of decyanoethylation. Under similar conditions certain derivatives of *N*-(β-cyanoethyl)indole yield the corresponding indole derivatives[211].

The cyanoethyl group attached to nitrogen in indole, or the more stable one in the β-position can thus both be eliminated. The migration of the cyanoethyl group from the nitrogen atom to the β-position in indole has not been effected[212].

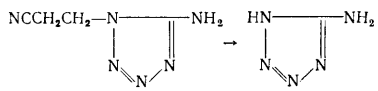
It seems that the hydrolysis of *N*-(β-cyanoethyl)gramine to the corresponding amino-acid is accompanied by decomposition[213]. Under specified conditions *N*-(β-cyanoethyl)-indoline may yield indoline and acrylonitrile[214,215].

Heated with aqueous solutions of acids or alkalis the cyanoethyl derivative of benzimidazole undergoes decyanoethylation to benzimidazole[216]:



The cyanoethyl group, however, could not be eliminated from the cyanoethyl derivative of 2-methylbenzimidazole.

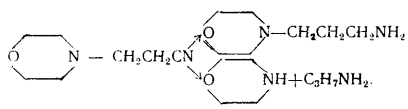
Hydrolysis of 1-(β-cyanoethyl)-5-aminotetrazole with aqueous barium hydroxide is accompanied by decyanoethylation[44]:



Pyrolysis of 1-(β-cyanoethyl)-6-methyl-2-pyridone yields 6-methyl-2-pyridone and acrylonitrile[217].

The cyanoethyl derivative of piperidine must be distilled rapidly *in vacuo*, since slow distillation results in partial decyanoethylation[65]. Decyanoethylation is also observed on heating β-(*N*-piperidyl)propionitrile in ethylene glycol[166].

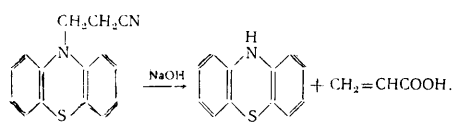
On reduction β-(*N*-cyanoethyl)morpholine forms, in addition to other products, morpholine and propylamine[58]:



Decyanoethylation occurs during the oxidation of *N*-(β-cyanoethyl)anabasine by means of potassium permanganate. This reaction is taken as evidence of the structure of anabasine[67].

Attempts to remove the cyanoethyl group from 1-(β-cyanoethyl)-4-keto-1,2,3,4-tetrahydroquinoline using alkali have failed. In the presence of a mixture of concentrated hydrochloric acid and excess acetic anhydride, however, 1-acetyl-4-keto-1,2,3,4-tetrahydroquinoline was isolated[205].

Smith[218] made an effort to hydrolyse the cyanoethyl derivative of phenothiazine by heating it with sodium hydroxide in aqueous ethylene glycol. Instead of the carboxyethyl derivative, however, he isolated phenothiazine and acrylic acid (the latter, in the author's opinion, being formed by dehydration of β-hydroxypropionic acid):



Smith obtained the carboxyethylphenothiazine by hydrolysis of the corresponding cyanoethyl derivative with alkali in aqueous methanol. It was later shown, however, that under these conditions considerable decyanoethylation takes place[219]. Smith himself[220] observed this in the case of the oxidation product from *N*-(β-cyanoethyl)phenothiazine.

Alkaline hydrolysis of β-cyanoethyl phenoselenazine yields the carboxyethyl derivative, while by acid hydrolysis the product of decyanoethylation is formed[221].

Decyanoethylation takes place during the hydrolysis of the cyanoethylphenoxazine with caustic soda in ethanol[222]. Under these conditions *N*-(β-cyanoethyl)benzophenothiazine simultaneously undergoes hydrolysis and decyanoethylation.

Certain cyanoethyl derivatives of heterocyclic nitrogen bases were used for introducing the cyanoethyl group into other compounds. Thus, *N*-(β-cyanoethyl)pyrrolidine and *N*-(β-cyanoethyl)morpholine methiodides with potassium cyanide formed succinic dinitrile[60]. Cyanoethylation of aromatic amines has been effected by means of *N*-(β-cyanoethyl)pyrrolidine[60], *N*-(β-cyanoethyl)piperidine[19], and *N*-(β-cyanoethyl)morpholine[60]. However, the transcyanoethylation does not take place during the reaction of aniline with 1,4-di-(β-cyanoethyl)-2,5-diketopiperazine. Only by adding small amounts of an alkali hydroxide or triethylamine was it possible to isolate traces of β-(phenylamino)propionitrile[202,223].

The reversibility of the reaction of *N*-(α-cycloalkenyl)pyrrolidines with acrylonitrile has been reported[224].

6. THE BOND BETWEEN A CYANOETHYL GROUP AND PHOSPHORUS

The bond between a cyanoethyl group and phosphorus has been studied in the case of the mono-, di-, and tri-cyanoethyl phosphines as well as of their *P*-substituted derivatives. Although Rauhut and his associates[225] were unsuccessful in their attempts to remove the cyanoethyl group from these compounds, other American workers[226] showed that decyanoethylation and transcyanoethylation are possible in case of *P*-cyanoethyl compounds.

7. THE BOND BETWEEN A CYANOETHYL GROUP AND CARBON

If during cyanoethylation the cyanoethyl group becomes attached to a carbon atom, it can only be removed with difficulty.

Chloroform reacts with acrylonitrile in the presence of alkali at 0°−5°, yielding not more than 12% cyanoethylated derivative. The low yield is taken to indicate the reversibility of this reaction[1,227,228]:

$$CHCl_3 + CH_2{=}CHCN \rightleftarrows Cl_3C{-}CH_2CH_2CN.$$

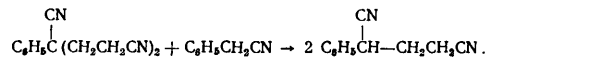
Under similar conditions bromoform yields only 5% of cyanoethyl derivative.

Acrylonitrile reacts with compounds containing mobile hydrogen atoms in methylene or methyl groups, yielding mainly the di- and tri-cyanoethyl derivatives. Even in the presence of an excess of the substance undergoing cyanoethylation, the yield of monocyanoethyl derivative is usually small. However, under certain conditions (high temperature, small amounts of sodium cyanide and water), the reaction can be arrested at the monocyanoethylation stage[229-231]. The monocyanoethylation of a series of ketones with acrylonitrile has been carried out in the presence of amines, amino-alcohols, and Schiff's bases[232-234], in 80−95% yields. It should be noted that the *C*-monocyanoethyl compounds are obtained either under very mild conditions or, as above, under more vigorous conditions than the corresponding di- and tri-cyanoethyl derivatives. In the latter case the high temperature and other conditions seem to favour the reverse process, *viz.* decyanoethylation. If a compound easy to cyanoethylate, *e.g.* an amine, is added to the reaction mixture, transcyanoethylation may also take place.

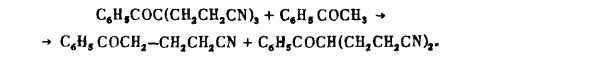
It is most interesting that if during the monocyanoethylation of diisopropyl ketone with acrylonitrile the reaction mixture is treated with small amounts of the reaction product, *viz.* the monocyanoethyl diisopropyl ketone, the yield of the latter compound is increased from 33 to 70%.[235]

In the reaction of acrylonitrile with phenyl benzyl sulphone, in dioxane at 80°, and in the presence of alcoholic sodium ethoxide, the methylene group only forms the monocyanoethyl derivative, since the dicyanoethyl compound is unstable under these conditions[1,3].

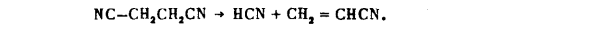
On hydrogenation of 1, 2, 3, 6-tetramethyl-3-cyanoethyl--4-piperidone at 100°–120° in the presence of Raney nickel a considerable amount of a compound, which has been assigned the structure of 1, 2, 3, 6-tetramethylpiperidine, is obtained[236]. On hydrogenation over copper chromite, the dicyanoethyl derivative of phenylacetonitrile (220°, 175 atm) forms β-phenylpiperidine[237]. Heated 3 h with phenylacetonitrile at 225° in the presence of a small amount of sodium cyanide, the same compound yields the corresponding monocyanoethyl derivative[231]:



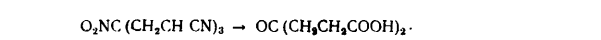
Under the same conditions acetophenone reacts with its tricyanoethyl derivative forming mono- and di-cyanoethylated products:



Under certain conditions succinic dinitrile (the cyanoethylation product from hydrocyanic acid) decomposes into hydrocyanic acid and acrylonitrile (94%):[3,238–240]



On alkaline hydrolysis the tricyanoethyl derivative of nitromethane splits off one molecule of acrylonitrile forming γ-ketopimelic acid[3]:



Although in tricyanoethylacetone all cyanoethyl groups are attached to the same carbon atom, the compound has withstood all efforts at decyanoethylation or transcyanoethylation. Heating 1, 1, 1-tri-(β-cyanoethyl)acetone to 150° with acetone in the presence of potassium hydrazide, or to 200° in the presence of sodium methoxide or diethylamine, gave only the starting compounds and small amounts of resin[113].

Attempts to obtain the monocyanoethyl derivative of ethyl methyl acetone from ethyl methyl ketone and its dicyanoethyl derivative have also failed[241].

It was shown above that the reaction of aromatic amines with β-alkoxy-, β-aryloxy-, β-alkylmercapto-, and β--alkylamino-propionitriles yields β-arylaminopropionitriles. Transcyanoethylation does not occur, however, when aniline is made to react with compounds containing cyanoethyl groups attached to a carbon atom, *e.g.* 1, 1, 1--tri(β-cyanoethyl)acetone, 2, 2, 6, 6-tetra-(β-cyanoethyl)-cyclohexanone, *etc.*[19].

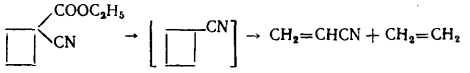
Although the thermal decomposition of polystyrene, rubber, polymethylmethacrylate, and certain other polymers involves the formation of the corresponding monomers, no depolymerisation occurs in the case of polyacrylonitrile. Polyacrylonitrile is very resistant to heat, and remains unchanged up to 300°. It decomposes at higher temperatures, without forming acrylonitrile[242].

8. MISCELLANEOUS CASES OF TRANSCYANOETHYLATION, DECYANOETHYLATION, AND THE FORMATION OF ACRYLONITRILE

The reaction product from acrylonitrile or ethylene cyanohydrin and furfural, furfurylideneacryl amide, may act as a cyanoethylating agent in the reaction with compounds containing a mobile hydrogen atom[243].

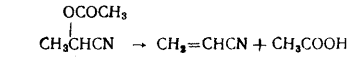
On heating, the Diels–Alder reaction between tetraphenylcyclopentadienone and acrylonitrile is reversed[244].

Pyrolysis of 1-cyano-1-ethoxycarbonylcyclobutane at 520° yields 56% of acrylonitrile[245]:



Acrylonitrile was also observed among the pyrolysis products from 1-cyano-2, 2-dimethyl-3-methylenecyclobutane[246].

Passing the vapours of β-alkoxypropionamide over silica gel at 350°–500° results in the formation of acrylonitrile[247]. Acrylonitrile was also obtained in 40% yield by the pyrolysis of β-methoxypropionamide[248], and during the pyrolysis of α-chloro-, α-hydroxy-, and α-acetoxy-propionitriles[1]. In the presence of catalysts at 620° the last compound yields 90% or more of acrylonitrile[249]:



There are no data in the literature on the cleavage of the bond between the β-cyanoethyl group and silicon. It was recently shown, on the contrary, that the *Si*–cyanoethyl compounds are resistant to high temperatures, alkalis, and acids, and that they do not lend themselves to decyanoethylation or transcyanoethylation reactions[250,251].

SUMMARY

The bond of the β-cyanoethyl group with oxygen, sulphur, nitrogen, carbon, *etc.* is as a rule more labile than the bonds between other alkyl radicals and these atoms. The β-cyanoethyl group is more mobile than other groups or alkyl radicals. To a certain extent this can be explained by the considerable tendency of acrylonitrile and its derivatives to form systems with conjugated multiple bonds. The conversion of the cyanoethyl compounds to corresponding amides, alkoxycarbonyl and carboxyethyl compounds lowers reactivity, *e.g.* in dealkylation and transalkylation. This difference is more prominent in compounds which are unable to form systems of conjugated multiple bonds. The conversion of the cyanoethyl compounds to corresponding amides, alkoxycarbonyl and carboxyethyl compounds lowers reactivity, *e.g.* in dealkylation and transalkylation. This difference is more prominent in compounds which are unable to form systems of conjugated multiple bonds.

1. A. P. Terent'ev and A. N. Kost, "Reaktsii i Metody Issledovaniya Organicheskikh Soedinenii" (Reactions and Methods of Investigation of Organic Compounds), Vol. 2. Goskhimizdat, Moscow–Leningrad, 1952, p. 47.
2. H. Bruson, "Organic Reactions", Vol. 5, New York, 1949, p. 79.
3. O. Bayer, Angew Chem., 61, 229 (1949).

4. N. S. Vul'fson (Editor), "Preparative Organic Chemistry" (Translated into Russian), Goskhimizdat, Moscow, 1959, p. 586.
5. P. Du Brow and H. Harwood, J. Org. Chem., 17, 1043 (1952).
6. P. Du Brow and H. Harwood, U. S. P. 2627526 (1953); Ref. Zhur. Khim., 47292 (1954).
7. U. S. P. 2762836 (1956); Chem. Zentr., 16479 (1959).
8. V. Nekrasov, J. prakt. Chem., [2] 117, 211 (1927).
9. V. Nekrasov, Zhur. Russ. Fiz.-Khim. Obshch., 59, 921 (1927).
10. S. Heininger, U. S. P. 2870153 (1959); Chem. Abs., 53, 11416 (1959).
11. S. Keimatsu and S. Sugasawa, J. Pharm. Soc. Japan, 48, 101; Chem. Zentr., II, 1881 (1928).
12. J. Olin and T. Johnson, J. Amer. Chem. Soc., 53, 1475 (1931).
13. H. Henze and T. Thompson, J. Amer. Chem. Soc., 65, 1422 (1943).
14. A. N. Kost and V. G. Yashunskii, Zhur. Obshch. Khim., 23, 230 (1953).
15. L. Barkley and R. Levine, J. Amer. Chem. Soc., 72, 3699 (1950).
16. V. Boekelheide, J. Amer. Chem. Soc., 69, 790 (1947).
17. J. Roberts and K. Selby, J. Chem. Soc., 2335 (1951).
18. S. Heininger, J. Org. Chem., 22, 704 (1957).
19. P. F. Butskus and G. I. Denis, Nauch. Dokl. Vys. Shkoly, Khim. i Khim. Tekhnol., No. 4, 743 (1958).
20. P. F. Butskus, Thesis (Ph. D. Equivalent), Moscow State University, 1954.
21. A. P. Terent'ev and P. F. Butskus, Zhur. Obshch. Khim., 27, 2591 (1957).
22. P. F. Butskus, Izv. Vys. Ucheb. Zaved., Khim. i Khim. Tekhnol., 3, 122 (1960).
23. P. F. Butskus, G. A. Denis, and A. I. Butskene, Izv. Vys. Ucheb. Zaved., Khim. i Khim. Tekhnol., 3, 469 (1960).
24. I. P. Tsukervanik, "Voprosy Khimicheskoi Kinetiki, Kataliza i Reaktsionnoi Sposobnosti" (Chemical Kinetics, Catalysis, and Reactivity), Izd. Akad. Nauk SSSR, Moscow, 1955, p. 608.
25. I. P. Tsukervanik, "Issledovaniya v Oblasti Alkilirovaniya Yadra Aromaticheskikh Soedinenii" (Nuclear Alkylation of Aromatic Compounds), Izd. Erevansk. Univ., 1955, p. 61.
26. A. D. Grebenyuk and I. P. Tsukervanik, Zhur. Obshch. Khim., 25, 286 (1955).
27. H. Johnston, U. S. P. 2789995 (1957); Chem. Abs., 52, 1242 (1958).
28. H. Johnston and F. Gross, J. Org. Chem., 22, 1264 (1957).
29. L. Behr, J. Kirby, R. MacDonald, and C. Todd, J. Amer. Chem. Soc., 68, 1296 (1946).
30. G. Schmir, L. Cohen, and B. Witkop, J. Amer. Chem. Soc., 81, 2228 (1959).
31. G. Koelsch and H. Hood, J. Org. Chem., 20, 1282 (1955).
32. W. Langley and R. Adams, J. Amer. Chem. Soc., 44, 2320 (1922).
33. E. Chapman and H. Stephen, J. Chem. Soc., 885 (1925).
34. A. N. Kost, B. M. Sheiman, and A. P. Terent'ev, Zhur. Obshch. Khim., 29, 2310 (1959).
35. S. Heininger, U. S. P. 2819291 (1958); Ref. Zhur. Khim., 65312 (1959).
36. J. Teter and J. Mostek, U. S. P. 2552072 (1951); Chem. Abs., 46, 130 (1952).
37. French P. 794255 (1935); Chem. Zentr., I, 4074 (1936).
38. O. Bauer and J. Teter, U. S. P. 2443292 (1948); Chem. Abs., 42, 7323 (1948).
39. W. Utermohlen and C. Hamilton, J. Amer. Chem. Soc., 63, 156 (1941).
40. J. Zech, U. S. P. 2833757 (1959); Ref. Zhur. Khim., 75695 (1959).
41. A. F. Bekhli, Zhur. Obshch. Khim., 27, 698 (1957).
42. A. F. Bekhli, Dokl. Akad. Nauk SSSR, 101, 679 (1955).
43. E. Münch and O. Schlichting, German P. 561156 (1930); Chem. Zentr., II, 443 (1933).
44. D. Renn and R. Herbst, J. Org. Chem., 24, 473 (1959).
45. H. Dreifus, B. P. 344420, 344480, 344488 (1931); Chem. Zentr., I, 1179 (1932).
46. F. King and R. Beer, J. Chem. Soc., 791 (1945).
47. F. Bergel, A. Morrison, and H. Rinderknecht, U. S. P. 2446803 (1948); Chem. Abs., 43, 695 (1949).
48. A. D. Petrov, S. I. Sadykh-Zade, and M. V. Vdovin, Dokl. Akad. Nauk SSSR, 100, 711 (1959).
49. R. Miller, J. Bradley, and L. Hamilton, J. Amer. Chem. Soc., 78, 5299 (1956).
50. Kato, Isikhara, and Kanon, Jap. P. 1578 (1954); Ref. Zhur. Khim., 1870 (1958).
51. B. A. Arbuzov and B. P. Lugovkin, Zhur. Obshch. Khim., 21, 99 (1951).
52. A. N. Kost and V. V. Ershov, Zhur. Obshch. Khim., 26, 3132 (1956).
53. A. P. Terent'ev, A. N. Kost, and S. M. Gurvich, Zhur. Obshch. Khim., 23, 615 (1953).
54. L. Spence, U. S. P. 2385549 (1945); Chem. Abs., 40, 594 (1946).
55. P. F. Butskus, Zhur. Obshch. Khim., 30, 1818 (1960).
56. N. Sperber and R. Fricano, J. Amer. Chem. Soc., 75, 2986 (1953).
57. H. Irie, Y. Tsuda, and S. Uyeo, J. Chem. Soc., 1446 (1959).
58. F. Whitmore, H. Mosher, R. Adams, R. Taylor, E. Chapin, C. Weisel, and W. Janko, J. Amer. Chem. Soc., 66, 725 (1944).
59. A. D. Petrov and V. V. Vdovin, Zhur. Obshch. Khim., 29, 2910 (1959).
60. R. Bates, J. Cymerman-Craig, M. Moyle, and R. Young, J. Chem. Soc., 388 (1956).
61. Takamisava, Jap. P. 3811 (1955); Ref. Zhur. Khim., 5577 (1957).
62. P. F. Butskus, Izv. Vys. Ucheb. Zaved., Khim. i Khim. Tekhnol., 2, 51 (1959).
63. L. Boatright, U. S. P. 2734081 (1956); Ref. Zhur. Khim., 20569 (1957).
64. J. Dixon and E. Cook, U. S. P. 2439359 (1948); Chem. Abs., 42, 5047 (1948).
65. A. N. Kost, Ucheb. Zap. Moskov. Univ., VI, 131, 37 (1950).
66. A. P. Terent'ev and A. N. Kost, Zhur. Obshch. Khim., 18, 510 (1948).
67. E. Kh. Timbekov and A. S. Sadykov, Zhur. Obshch. Khim., 25, 786 (1955).
68. V. G. Chelintsev, Z. V. Benevolenskaya, and B. M. Dubinin, Zhur. Obshch. Khim., 17, 269 (1947).
69. V. G. Chelintsev and Z. V. Benevolenskaya, Zhur. Obshch. Khim., 14, 1142 (1944).
70. V. G. Chelintsev, B. M. Dubinin, and Z. V. Benevolenskaya, Zhur. Obshch. Khim., 17, 273 (1947).
71. S. P. Motornyi, L. I. Kirenskaya, and N. N. Yarovenko, Zhur. Obshch. Khim., 29, 2157 (1959).
72. A. Yakubovich, V. Razumovskii, and S. Rozenshtein, Zhur. Obshch. Khim., 28, 2292 (1958).
73. Beilstein's Handbuch, 3, 298 (4th Edition).
74. N. Kartinos, U. S. P. 2811544 (1957); Ref. Zhur. Khim., 68736 (1959).
75. N. Kartinos and J. Normington, U. S. P. 2806872 (1957); Chem. Zentr., 2622 (1959).
76. E. Cherbuliez and J. Rabinowitz, German P. 1050745 (1959); Chem. Zentr., 13941 (1959).
77. E. Cherbuliez and J. Rabinowitz, Helv. Chim. Acta, 39, 1461 (1956).
78. G. Clemo and E. Walton, J. Chem. Soc., 723 (1928).

79. P. Ritchie, D. Jones, and R. Burns, B. P. 424 885 (1933); Chem. Zentr., I, 2439 (1936).
80. R. Burns, D. Jones, and P. Ritchie, J. Chem. Soc., 400 (1935).
81. P. Ritchie, J. Chem. Soc., 1054 (1935).
82. J. Lichty, U. S. P. 2 208 328 (1940); Chem. Abs., 35, 139 (1941).
83. E. Sakellarios, Helv. Chim. Acta, 29, 1675 (1946).
84. S. Miller and W. Groombridge, U. S. P. 2 452 672 (1949); Chem. Abs., 43, 2220 (1949).
85. E. V. Kuznetsov and R. K. Valetdinov, Trudy Kazan. Khim.--Tekhnol. Inst., 23, 167 (1957).
86. H. Bruson and W. Niederhauser, U. S. P. 2 437 906 (1948); Chem. Abs., 42, 4196 (1948).
87. A. P. Terent'ev, A. N. Kost, and V. A. Smit, Zhur. Obshch. Khim., 25, 1959 (1955).
88. N. Minne and H. Adkins, J. Amer. Chem. Soc., 55, 299 (1933).
89. J. Lynn, German P. 1 061 311 (1959); Chem. Zentr., 3377 (1960).
90. A. P. Terent'ev, P. F. Butskus, and V. G. Yashunskii, Zhur. Anal. Khim., 9, 162 (1954).
91. W. Watanabe and L. Conlon, U. S. P. 2 760 990 (1956); Ref. Zhur. Khim., 5645 (1959).
92. W. Watanabe and L. Conlon, J. Amer. Chem. Soc., 79, 2828 (1957).
93. Austrian P. 191 431 (1957); Chem. Zentr., 7968 (1959).
94. J. MacGregor and C. Pugh, J. Chem. Soc., 535 (1945).
95. A. P. Terent'ev, A. N. Kost, and A. M. Berlin, Zhur. Obshch. Khim., 26, 719 (1956).
96. A. Takamizawa, J. Pharm. Soc. Japan, 74, 759 (1954); Ref. Zhur. Khim., 49 543 (1959).
97. N. Seeger, U. S. P. 2 393 000 (1946); Chem. Abs., 40, 2465 (1946).
98. L. Soffer and E. Parrotta, J. Amer. Chem. Soc., 76, 3580 (1954).
99. L. Soffer, M. Katz, and E. Parrotta, J. Amer. Chem. Soc., 78, 6120 (1956).
100. W. Utermohlen, J. Amer. Chem. Soc., 67, 1505 (1945).
101. R. Christian, H. Brown, and R. Hixon, J. Amer. Chem. Soc., 69, 1961 (1947).
102. F. Buckle and B. Saunders, J. Chem. Soc., 2774 (1949).
103. I. N. Nazarov and G. A. Shvekhgeimer, Zhur. Obshch. Khim., 24, 157 (1954).
104. I. N. Nazarov, G. A. Shvekhgeimer, and V. A. Rudenko, Zhur. Obshch. Khim., 24, 329 (1954).
105. R. Christian and R. Hixon, J. Amer. Chem. Soc., 70, 1333 (1948).
106. I. N. Nazarov and G. A. Shvekhgeimer, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 1221 (1956).
107. J. Paden and P. Kirk, U. S. P. 2 335 605 (1943); Chem. Abs., 38, 2970 (1944).
108. R. Dean, U. S. P. 2 335 653 (1943); Chem. Abs., 38, 2970 (1944).
109. Houben–Weyl, "Methoden der organischen Chemie", Vol. 8, Stuttgart, 1952, p. 539.
110. H. Zahn and W. Gerstner, Chem. Ber., 88, 1731 (1955).
111. German P. 1 003 740 (1957); Chem. Abs., 53, 18 867 (1959).
112. E. Cook and P. Moss, U. S. P. 2 425 693 (1947); Chem. Abs., 41, 7410 (1947).
113. A. P. Terent'ev, A. N. Kost, and S. M. Gurvich, Zhur. Obshch. Khim., 22, 1977 (1952).
114. R. Oda, M. Nomura, and S. Tanimoto, Bull. Inst. Chem. Res., Kyoto Univ., 32, 231 (1954); Chem. Abs., 50, 7112 (1956).
115. P. F. Butskus and G. A. Denis, Zhur. Obshch. Khim., 30, 1321 (1960).
116. O. Wiedeman and W. Montgomery, J. Amer. Chem. Soc., 67, 1994 (1945).
117. G. Journeay, U. S. P. 2 790 821 (1957); Chem. Abs., 51, 15 550 (1957).
118. G. Journeay, U. S. P. 2 790 818 (1957); Chem. Abs., 51, 15 573 (1957).
119. G. Journeay, U. S. P. 2 770 640 (1956); Chem. Abs., 51, 8792 (1957).
120. L. Rapoport, U. S. P. 2 832 798 (1958); Chem. Abs., 52, 16 195 (1958).
121. Z. A. Rogovin, Uspekhi Khim., 28, 856 (1959).
122. C. Berther, Chem. Ber., 92, 2616 (1959).
123. A. Montagna and E. Stout, U. S. P. 2 853 510 (1958); Ref. Zhur. Khim., 35 786 (1960).
124. C. Allen and J. Van Allan, J. Org. Chem., 14, 754 (1949).
125. A. G. Yashunskaya, Z. A. Rogovin, and A. A. Berlin, Zhur. Prikl. Khim., 28, 105 (1956).
126. J. Wright and L. Minsk, J. Amer. Chem. Soc., 75, 98 (1953).
127. M. Negishi, I. Sekiguchi, and S. Okada, Sen–Igaku Kaishi, 12, 479 (1956); Chem. Abs., 51, 8040 (1957).
128. O. Moe, S. Miller, and M. Buckley, J. Amer. Chem. Soc., 74, 1325 (1952).
129. S. N. Danilov and A. A. Lopatenok, Zhur. Obshch. Khim., 28, 3184 (1958).
130. T. Takahashi, M. Hori, and K. Okumara, J. Pharm. Soc. Japan, 78, 1 (1958); Ref. Zhur. Khim., 1199 (1959).
131. H. Wassermann, B. Suryanarayana, and D. Grassetti, J. Amer. Chem. Soc., 78, 2808 (1956).
132. O. Grummitt and D. Marsh, J. Amer. Chem. Soc., 71, 4156 (1949).
133. J. Grigging and L. Salisbury, J. Amer. Chem. Soc., 70, 3416 (1948).
134. E. Simpson, M. Tomlinson, and H. Taylor, J. Chem. Soc., 2239 (1951).
135. A. Hardman, J. Amer. Chem. Soc., 70, 2119 (1948).
136. T. Coffield, A. Filbey, G. Ecke, and A. Kolka, J. Amer. Chem. Soc., 79, 5019 (1957).
137. N. Campbell and A. Fairfull, J. Chem. Soc., 1239 (1949).
138. G. Misra and R. Asthana, Annalen, 609, 240 (1957).
139. E. Cherbuliez and J. Rabinowitz, Helv. Chim. Acta, 39, 1844 (1956).
140. E. Cherbuliez, H. Probst, J. Rabinowitz, and S. Sandrin, Helv. Chim. Acta, 41, 1163 (1958).
141. P. Gilham and G. Tener, Chem. and Ind., 542 (1959).
142. E. V. Kuznetsov and R. K. Valetdinov, Trudy Kazan. Khim.--Tekhnol. Inst., 23, 174 (1957).
143. G. Clemo and G. Ramage, J. Chem. Soc., 49 (1931).
144. G. Clemo, J. Ormston, and G. Ramage, J. Chem. Soc., 3185 (1931).
145. M. Weiss and M. O'Donoghue, J. Amer. Chem. Soc., 79, 4771 (1957).
146. R. Clinton, C. Suter, S. Laskowski, M. Jackman, and W. Huber, J. Amer. Chem. Soc., 67, 594 (1945).
147. O. Achmatowicz and J. Michalski, Roczniki Chem., 30, 243 (1956).
148. A. P. Terent'ev, K. I. Chursina, and A. N. Kost, Zhur. Obshch. Khim., 20, 1073 (1950).
149. J. Ford, S. Buc, and J. Greiner, J. Amer. Chem. Soc., 69, 844 (1947).
150. F. Kung, U. S. P. 2 401 429 (1946); Chem. Abs., 40, 5447 (1946).
151. E. Smolin and L. Beegle, Ind. Eng. Chem., 50, 1115 (1958).
152. S. Buc, J. Ford, and E. Wise, J. Amer. Chem. Soc., 67, 92 (1945).
153. "Organic Syntheses" (Translated into Russian), Inostr. Lit., Moscow, Vol. IV, 1953, p. 46; Org. Synth., 27, 3 (1947).
154. Houben–Weyl, "Methoden der organischen Chemie", Vols. II/I, Stuttgart, 1957, p. 272.
155. P. Kirk, U. S. P. 2 334 163; Chem. Abs., 38, 2667 (1944).
156. S. Chodroff, R. Kapp, and C. Beckmann, J. Amer. Chem. Soc.,

69, 256 (1947).
157. W. Schmidt-Nickels, J. prakt. Chem., [4], 6, 139 (1958).
158. W. Schmidt-Nickels, U. S. P. 2 794 805 (1957); Chem. Zentr., 2623 (1959).
159. M. Mugno and M. Bornengo, Gazzetta, 86, 451 (1956).
160. A. N. Kost, S. I. Suminov, and V. V. Ershov, Zhur. Obshch. Khim., 30, 498 (1960).
161. A. Clifford and J. Lichty, U. S. P. 2 368 521 (1945); Chem. Abs., 40, 352 (1946).
162. L. Kissinger and M. Schwartz, J. Org. Chem., 23, 1342 (1958).
163. K. Taylor, W. Selcer, P. Montgomery, and R. Hughes, J. Amer. Chem. Soc., 81, 5333 (1959).
164. C. Mannich and E. Ganz, Ber., 55, 3486 (1922).
165. D. Tarbell, N. Shakespeare, C. Claus, and J. Bunnett, J. Amer. Chem. Soc., 68, 1217 (1946).
166. P. F. Butskus, Izv. Vys. Ucheb. Zaved., Khim. i Khim. Tekhnol., 3, 1108 (1960).
167. A. F. Bekhli, Zhur. Obshch. Khim., 21, 86 (1951).
168. A. F. Bekhli, Zhur. Obshch. Khim., 28, 204 (1958).
169. G. Bachman and R. Mayhew, J. Org. Chem., 10, 245 (1945).
170. J. King and F. McMillan, J. Amer. Chem. Soc., 68, 1468 (1946).
171. L. Bradford, E. Meek, J. Turnbull, and W. Wilson, Chem. and Ind., 839 (1951).
172. I. N. Nazarov and S. I. Zav'yalov, Zhur. Obshch. Khim., 24, 469 (1954).
173. T. Shono and R. Oda, J. Chem. Soc. Japan, 60, 21 (1957); Ref. Zhur. Khim., 39 716 (1958).
174. R. Bates and J. Cymerman-Craig, J. Chem. Soc., 1153 (1954).
175. L. Bauer and J. Cymerman, Chem. and Ind., 615 (1951).
176. L. Bauer, J. Cymerman, and W. Sheldon, J. Chem. Soc., 3311 (1951).
177. J. Cymerman-Craig, M. Moyle, A. Nicholson, and R. Werner, J. Chem. Soc., 3628 (1955).
178. J. Cymerman-Craig and M. Moyle, Org. Synth., 36, 6 (1956).
179. "Organic Syntheses" (Translated into Russian), Inostr. Lit., Moscow, Vol. 8, 1958, p. 81. [Probably translation of ref. 178 (Ed. of Translation)].
180. A. N. Kost, Yu. V. Konnova, V. V. Ershov, and E. G. Rukhadze, Zhur. Obshch. Khim., 29, 498 (1959).
181. A. N. Kost, V. V. Ershov, and S. I. Suminov, Zhur. Obshch. Khim., 27, 2514 (1957).
182. W. Schuller and D. Guth, J. Org. Chem., 23, 1047 (1958).
183. L. Pursglove, J. Org. Chem., 24, 576 (1959).
184. L. Pursglove, U. S. P. 2 885 435 (1959); Chem. Abs., 53, 21 698 (1959).
185. S. Petersen and E. Müller, Ber., 81, 31 (1948).
186. A. E. Kretov and N. P. Romazanovich, Zhur. Obshch. Khim., 28, 1059 (1958).
187. A. E. Kretov and N. P. Romazanovich, Ukrain. Khim. Zhur., 24, 761 (1958).
188. J. Lynn, J. Amer. Chem. Soc., 78, 5829 (1956).
189. G. Misra and R. Asthana, J. prakt. Chem., [4], 3, 4 (1956).
190. G. Misra and R. Asthana, J. prakt. Chem., [4], 4, 270 (1957).
191. H. Bruson and T. Riener, J. Amer. Chem. Soc., 70, 214 (1948).
192. A. A. Strepikheev and M. N. Bogdanov, Zhur. Obshch. Khim., II, 1467 (1953).
193. P. F. Butskus and G. I. Denis, Zhur. Obshch. Khim., 30, 1317 (1960).
194. L. McKinney, E. Uhing, E. Setzkorn, and J. Cowan, J. Amer. Chem. Soc., 73, 1641 (1951).
195. L. McKinney, E. Setzkorn, and E. Uhing, J. Amer. Chem. Soc., 74, 1942 (1952).
196. L. McKinney, E. Uhing, E. Setzkorn, and J. Cowan, J. Amer. Chem. Soc., 74, 5183 (1952).
197. P. F. Butskus and N. V. Raguotena, Zhur. Obshch. Khim., 31, 3673 (1961).
198. A. P. Terent'ev and P. F. Butskus, Zhur. Obshch. Khim., 23, 1230 (1953).
199. P. F. Butskus, Izv. Vys. Ucheb. Zaved., Khim. i Khim. Tekhnol., 3, 124 (1960).
200. A. P. Terent'ev and P. F. Butskus, Dokl. Akad. Nauk SSSR, 97, 851 (1954).
201. G. Kenner and H. Khorana, J. Chem. Soc., 2076 (1952).
202. P. F. Butskus and G. I. Denis, Nauch. Dokl. Vys. Shkoly, Khim. i Khim. Tekhnol., No. 1, 130 (1958).
203. G. I. Denis and S. A. Machenis, "Trudy III Stud. Nauch.-tekhnol. Konfer. Pribaltiki BSSR", Riga, 1958, p. 50.
204. U. Hoffmann and B. Jacobi, German P. 598 185 (1931); Friedl., 20 (1), 346 (1935).
205. W. Johnson and W. De Acetis, J. Amer. Chem. Soc., 75, 2766 (1953).
206. A. F. Bekhli, Thesis (D. Sc. Equivalent), Author's summary, Moscow, 1959.
207. J. Allison, J. Braunholtz, and F. Mann, J. Chem. Soc., 403 (1954).
208. A. P. Terent'ev, A. N. Kost, and V. M. Potapov, Zhur. Obshch. Khim., 18, 82 (1948).
209. G. Proctor and R. Thomson, J. Chem. Soc., 2312 (1957).
210. H. Fischer and H. Loewe, Annalen, 615, 124 (1958).
211. A. N. Grinev, N. E. Rodzevich, and A. P. Terent'ev, Zhur. Obshch. Khim., 27, 1690 (1957).
212. A. P. Terent'ev, A. N. Kost, and V. A. Smit, Zhur. Obshch. Khim., 26, 557 (1956).
213. J. Bell and H. Lindwall, J. Org. Chem., 13, 547 (1948).
214. H. Rapoport and J. Tretter, J. Org. Chem., 23, 248 (1958).
215. B. Astill and V. Boekelheide, J. Org. Chem., 23, 316 (1958).
216. L. S. Efros and B. A. Porai-Koshits, Zhur. Obshch. Khim., 23, 697 (1953).
217. R. Adams and S. Schrecker, J. Amer. Chem. Soc., 71, 1186 (1949).
218. N. Smith, J. Org. Chem., 15, 1125 (1950).
219. E. Godefroi and E. Wittle, J. Org. Chem., 21, 1163 (1956).
220. N. Smith, J. Org. Chem., 16, 415 (1951).
221. P. Müller, N. Buu-Hoi, and R. Rips, J. Org. Chem., 24, 37 (1959).
222. P. Müller, N. Buu-Hoi, and R. Rips, J. Org. Chem., 24, 1699 (1959).
223. P. F. Butskus, Zhur. Obshch. Khim., 30, 1816 (1960).
224. G. Stork and H. Landesman, J. Amer. Chem. Soc., 78, 5128 (1956).
225. M. Rauhut, I. Hechenbleikner, H. Currier, F. Schaefer, and V. Wystrach, J. Amer. Chem. Soc., 81, 1103 (1959).
226. M. Grayson, P. Keough, and G. Johnson, J. Amer. Chem. Soc., 81, 4803 (1959).
227. H. Bruson, W. Hiederhauser, T. Riener, and W. Hester, J. Amer. Chem. Soc., 67, 601 (1945).
228. W. Niederhauser and H. Bruson, U. S. P. 2 379 097 (1945); Chem. Abs., 39, 4618 (1945).
229. A. Rogers, U. S. P. 2 460 536 (1949); Chem. Abs., 43, 3446 (1949).
230. A. Campbell, J. Chem. Soc., 1377 (1954).
231. A. Campbell and I. Stevens, J. Chem. Soc., 959 (1956).
232. H. Krimm, German P. 1 002 342 (1957); Ref. Zhur. Khim., 44 217 (1958).
233. French P. 1 156 181; Chem. Zentr., 12 700 (1959).
234. H. Krimm, U. S. P. 2 850 519 (1958); Chem. Abs., 53, 14 026 (1959).
235. R. Ya. Levina, N. P. Shusherina, M. Yu. Lur'e, and N. D. Orlova, Dokl. Akad. Nauk SSSR, 106, 279 (1956).
236. I. N. Nazarov, G. A. Shvekhgeimer, and V. A. Rudenko, Zhur. Obshch. Khim., 24, 319 (1954).

237. G. Badger, J. Cook, and T. Walker, J. Chem. Soc., 1141 (1949).
238. G. Ray, U. S. P. 2 407 848 (1946); Chem. Abs., 41, 987 (1947).
239. C. Harris, U. S. P. 2 410 820 (1946); Chem. Abs., 41, 1235 (1947).
240. C. Harris, U. S. P. 2 429 459 (1947); Chem. Abs., 42, 1962 (1948).
241. H. Baumgarten and R. Eifert, J. Amer. Chem. Soc., 75, 3015 (1953).
242. W. Kern and H. Fernow, J. prakt. Chem., [2], 160, 281 (1942).
243. W. Treibs, E. Profft, and G. Drechsler, J. prakt. Chem., [4], 2, 1 (1955).
244. R. Doering, R. Miner, L. Rothman, and E. Becker, J. Org. Chem., 23, 520 (1958).
245. W. Bailey and J. Daly, J. Amer. Chem. Soc., 81, 5397 (1959).
246. J. Drysdale, H. Stevenson, and W. Sharkey, J. Amer. Chem. Soc., 81, 4908 (1959).
247. H. Schulz and A. Pufahl, Canad. P. 510 228 (1955); Ref. Zhur. Khim., 45 664 (1957).
248. G. Armstrong, B. P. 703 398 (1954); Ref. Zhur. Khim., 10 737 (1956).
249. German P. 1 008 282 (1957); Chem. Abs., 53, 17 907 (1959).
250. R. Pike, J. McMahon, V. Jex, W. Black, and D. Bailey, J. Org. Chem., 24, 1939 (1959).
251. G. Cooper and M. Prober, J. Org. Chem., 25, 240 (1960).

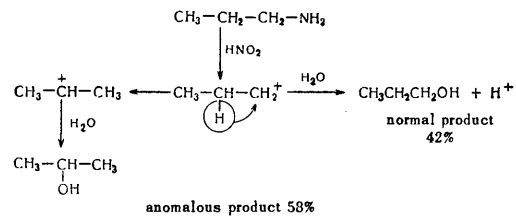
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NEW DATA ON HYDRIDE-TRANSFER REACTIONS

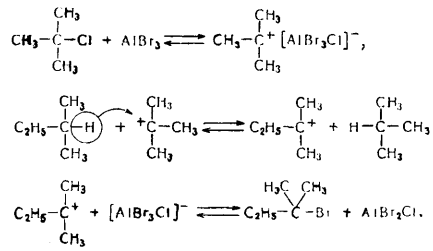
D. N. Kursanov and Z. N. Parnes

There are many organic reactions involving intermolecular transfer of hydrogen in the form of a proton. Such processes, which are fairly well understood, do not however constitute the only possible pathway for hydrogen transfer: in particular, a hydrogen nucleus associated with a pair of electrons may be transferred from one molecule to another. Processes of this sort are known as hydride-transfer reactions[1,2]. The present review is not concerned with the problem of the form and extent of association between a hydrogen nucleus and an electron pair in these reactions. However, the fairly high affinity of a hydrogen atom for an electron, 17.5 kcal mole^{-1}, suggests that such association may exist in hydride transfers[3].

As far as we know, the concept of intramolecular hydride transfer was first introduced in 1932 by Whitmore[4] to explain the anomalous course of reactions which may involve the formation of carbonium ions as intermediates. According to Whitmore, the latter isomerise through intramolecular hydride transfers. For example, Whitmore gives the following explanation of the formation of isopropanol, in addition to n-propanol, when nitrous acid reacts with n-propylamine:



The concept of intermolecular hydride transfer was introduced by Bartlett *et al.*[5] in 1944. They studied the reaction of isopentane with t-butyl chloride in the presence of aluminium bromide. Using an ingenious technique and apparatus, they shortened the time of contact of the components to 0.001 sec and obtained isopropyl bromide and isobutane. The reaction appears to involve intermolecular hydride transfer:



In recent years the concept of intermolecular and intramolecular hydride transfer has been widely employed to interpret the mechanism of complex reactions, and also to some extent in the search for new synthetic methods. Hydride transfers have been included in many mechanisms proposed for a large number of important organic reactions: the mechanism of the Meerwein–Ponndorf–Verley reaction proposed by Woodward *et al.*[6]; the mechanism of the Cannizzaro reaction proposed by Hammett[7]; the mechanism of the Tishchenko reaction proposed by Pfeil[8]; the mechanism of the Leuckart reaction proposed by Pollard and Young[9], and by Titov[10]; the mechanisms of aluminium chloride catalysed reactions of saturated hydrocarbons, proposed by Nenitzescu[2]; the mechanism of the isotopic hydrogen exchange in saturated hydrocarbons under the action of sulphuric acid, proposed by Otvos *et al.*[11], and a similar mechanism propsed by Kursanov and Setkina[12]; and many others.

In general, hydride transfer involves the transfer of a hydrogen nucleus with an electron pair, H: (subsequently to be called a hydride ion), from a donor to an acceptor. The acceptors are very often carbonium ions; the donors can belong to many different classes. When the migrating hydrogen atom is initially bound to a carbon atom, hydride transfer results in the formation of a new carbonium ion. Obviously the activity of a given substance as a hydride donor increases with increase in the stability of the corresponding carbonium ion.

A characteristic feature of the mechanisms quoted above and of many of the mechanisms discussed in a recent review by Deno *et al.*[13] is the fact that hydride transfer is effected through as powerful a hydride acceptor as the carbonium ion. This in fact frequently results in a certain arbitrariness of the proposed mechanisms,