

Alkyl Cyanates

VI. Chemical Reactions of Alkyl Cyanates

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The chemical reactions of alkyl cyanates have been studied in detail. One type of reaction is nucleophilic addition to the triple bond, such as the formation of urethans, thiourethans, selenourethans, isoureas and isobiurets, imidocarbonates, imidothiocarbonates, *N*-acylurethans, and thiourethans, formed respectively by the addition of water, hydrogen sulfide, hydrogen selenide, amines, phenols, thiols, carboxylic acids, and thiocarboxylic acids.

Another type of reaction is nucleophilic substitution in which the alkyl cyanates react as alkyl pseudohalides. Thus it was found that ethyl cyanate reacts with ethanol to form diethyl ether and cyanic acid (which in turn forms ethyl carbamate and ethyl allophanate). The unexpected formation of phenylurea in the reaction between aniline and ethyl cyanate, has been proved to take place by alkylation of aniline to ethylaniline and diethylaniline (identified by gas chromatography) and cyanic acid, which reacts with excess aniline to form phenylurea. Alkyl cyanates also react with hydrogen chloride to form alkyl chlorides and with nucleophilic anions to form the corresponding alkyl derivatives (alkyl iodides, azides, thiocyanates, nitrites, and nitro compounds). In these reactions the alkyl cyanates differ pronouncedly from the aryl cyanates.

Recently we have described the preparation of a series of alkyl cyanates.¹⁻⁵ By a curious coincidence the preparation of aryl cyanates were announced at almost the same time by Martin⁶⁻⁷ and by Grigat and Pütter.⁸⁻¹¹ The preparation of some sterically hindered aryl cyanates had already been described by Stroh and Gerber¹² and by Hedayatullah and Denivelle.¹³ Ethyl cyanate was also described by Martin,¹⁴ some halogensubstituted alkyl cyanates were described by Grigat and Pütter,⁸ and some sterically hindered alkyl cyanates by Kauer and Henderson.¹⁵ Thus, several representatives of this new class of compound, which chemists have tried in vain to prepare for about one hundred years, have suddenly become well known.

Since the alkyl cyanates represent a new class of compound we have found it worth while to screen their chemical properties on a rather broad basis. The chemical reactions of aryl cyanates have similarly been studied in detail by Martin¹⁸⁻²⁰ and by Grigat *et al.*^{8-11,21-28} Although, of course, the reactions of alkyl and aryl cyanates are in many respects analogous there are certain characteristic differences. As far as possible, we have tried to consider the papers by Martin and Grigat *et al.* although they appeared when most of the present work had been finished.*

The alkyl cyanates are comparable to alkyl halides or to esters of inorganic oxo-acids (alkyl sulfates etc.). Therefore one type of reactions to be expected is the potential dissociation into carbonium ions R^+ and cyanate ions NCO^- , which may lead to nucleophilic substitution reactions (S_N1 or S_N2) or to elimination reactions. The alkyl cyanates may, however, also be viewed upon as nitriles, and another type of reactions to be expected is therefore nucleophilic addition reactions to the triple bond. Which of these two types is the predominant one depends upon the reagent used, and in some cases both reactions will occur simultaneously.

A third type of reaction, namely the fission of the bond between RO and CN, is observed only in rare cases. Thus, alkyl cyanates react with hydrogen cyanide to form cyanogen. This reaction, however, also proceeds *via* an addition product.

The alkyl cyanates differ, of course, most pronouncedly from the aryl cyanates in the nucleophilic substitution reactions, since these reflect a difference of the same nature as that between alkyl and aryl halides.

The pseudohalogen character of the cyanate group is demonstrated by the reaction between ethyl cyanate and potassium iodide in nitromethane solution. Almost immediately after the addition of ethyl cyanate to a solution of potassium iodide in nitromethane, potassium cyanate (identified by its IR spectrum) begins to precipitate, and the reaction is completed according to the equation $\text{EtOCN} + \text{KI} \rightarrow \text{EtI} + \text{KOCN}$ in the course of one hour.

In the following, the reactions of alkyl cyanates with various other reagents are summarised.

1. The reaction between alkyl cyanates and water

The alkyl cyanates may add water to form alkyl carbamates (urethans). This process is catalysed both by acids and bases. When ethyl cyanate, dissolved in ether, is added with cooling to a concentrated aqueous solution of sodium hydroxide the smell of ethyl cyanate disappears immediately and from the ethereal solution ethyl carbamate could be isolated in a 96 % yield. In this respect, alkyl cyanates differ from aryl cyanates which according to Grigat and Pütter⁹ are hydrolysed by aqueous bases.

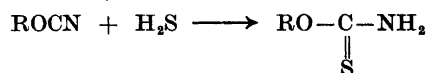
* Alkyl cyanates were prepared in this laboratory in 1962, *i.e.* two years before the first publications of Martin and Grigat *et al.* The formation of ethyl cyanate from 5-ethoxy-1,2,3,4-thiaziazole was mentioned in a review of thiaziazoles,²⁹ the manuscript of which was prepared in December 1962 — January 1963 and submitted for publication on March 20, 1963.

Alkyl cyanates are also transformed into carbamates by shaking their ethereal solutions with moist aluminium oxide.

Propyl cyanate was found to form propyl carbamate in a 50 % yield when added to concentrated hydrochloric acid. At the same time, propyl chloride (37 %) and cyamelide (8 %) were formed. The reaction of cyanates with acids under anhydrous conditions will be discussed below (3).

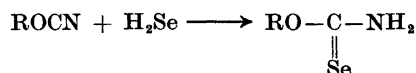
2. Reactions of alkyl cyanates with hydrogen sulfide or hydrogen selenide

Alkyl cyanates readily add hydrogen sulfide with the formation of *O*-alkyl thiocarbamates (thiourethans):



This reaction has been studied in detail in our earlier papers ^{1,3} and shown to be general.

Hydrogen selenide reacts in an analogous way with the formation of *O*-alkyl selenocarbamates (selenourethans):



However, when the cyanate is applied in excess, some unstable compounds are formed which seem to be bis(alkoxycarbonimidoyl)selenides, $(\text{RO}-\underset{\text{NH}}{\underset{\parallel}{\text{C}}})_2\text{Se}$.

3. The reaction of alkyl cyanates with anhydrous hydrogen chloride

The reaction of alkyl cyanates with hydrogen chloride was investigated in various solvents. In ether solution, propyl cyanate reacted with dry hydrogen chloride at room temperature to form propyl chloride, identified by gas chromatography, and cyanic acid which in turn polymerised to cyanuric acid. The gas chromatogram showed that no isopropyl chloride was formed. Similarly, isobutyl cyanate yielded only isobutyl chloride and no *tert*-butyl chloride.

The formation of cyanic acid as an intermediate in this reaction was demonstrated by adding 1-propanol or 2-propanol to the solution. These reacted with the cyanic acid formed from ethyl cyanate to form propyl carbamate, and isopropyl carbamate, respectively, in quantitative yields.

It was further observed that when the reaction between an alkyl cyanate and hydrogen chloride was performed in an inactive solvent at -80°C , cyamelide hydrochloride was formed instead of cyanuric acid. This accords with the products formed by polymerisation of cyanic acid at different temperatures.³⁰

The reaction between alkyl cyanates and hydrogen chloride in inactive solvents (ether, alkanes) invariably resulted in the formation of a certain

amount of carbamates or allophanates. These have probably been formed by reaction with traces of water although precautions were made to exclude water. The possibility was considered that hydrogen chloride might react to a certain extent with cyanates to form cyanogen chloride and an alcohol (*cf.* the reaction with hydrogen cyanide, 5), which then would react with the cyanic acid formed in the main reaction to give a carbamate or an allophanate. However, when ethyl cyanate was allowed to react with hydrogen chloride in a mass spectrometer strong peaks corresponding to $C_2H_5Cl^+$ and CH_2Cl^+ appeared at once, but no cyanogen chloride could be detected, nor was there any indication of the formation of an addition product of ethyl cyanate and hydrogen chloride, $C_2H_5O-C(=NH)Cl$, or an ion, $C_2H_5O-C\equiv NH^+$.

The reactions of alkyl cyanates with other strong inorganic proton acids have not been studied in detail. The formation of cyamelide or cyanuric acid when conc. sulfuric acid is added to ethyl cyanate dissolved in ether indicates, however, that the reactions proceed in a similar way as with hydrogen chloride.

These experiments show that alkyl cyanates behave quite differently from aryl cyanates which, according to Grigat and Pütter,⁸ are trimerised to triaryl cyanurates by proton acids.

4. Reaction of alkyl cyanates with Lewis acids

In contrast to proton acids, Lewis acids ($AlCl_3$, BF_3) cause polymerisation of alkyl cyanates, the main reaction products being trialkyl isocyanurates as was also found earlier^{1,3} for the basecatalyzed polymerisation of alkyl cyanates. This is a remarkable difference from the behaviour of aryl cyanates which according to Grigat and Pütter⁸ polymerise to cyanurates. The isocyanurates can easily be identified by the strong $C=O$ absorption in their infrared spectra.

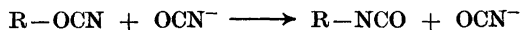
Polymerisation to isocyanurates also occurs by shaking an ethereal solution of an alkyl cyanate with anhydrous (ignited) aluminium oxide. Monomeric isocyanates could also be identified in these experiments. When moist aluminium oxide was used, the cyanates added water and formed alkyl carbamates.

5. Reaction of cyanates with nucleophilic anions

Alkyl cyanates may act as alkylating agents towards nucleophilic anions so that exchange reactions take place, *e.g.* the reaction with an inorganic iodide, mentioned in the introduction,

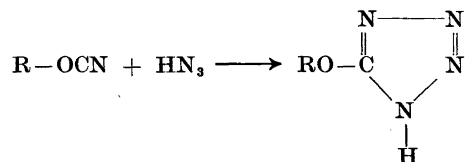


Similar reactions take place very easily with alkali cyanates or thiocyanates, only by shaking an ethereal solution of the cyanate with a concentrated aqueous solution of potassium cyanate or thiocyanate:

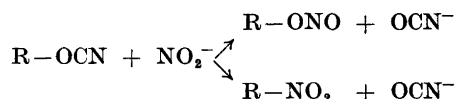


It is remarkable that in the case of these ambident ions the most nucleophilic site is the least electronegative atom (*cf.* Gould³¹), so that cyanate ions transform an alkyl cyanate into an isocyanate, whereas thiocyanate ions transform it into an alkyl thiocyanate.

With aqueous sodium azide an alkyl azide is formed; however, with hydrogen azide in ether solution addition takes place with the formation of an alkoxytetrazole:

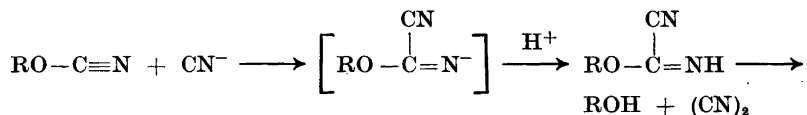


With aqueous sodium nitrite an alkyl cyanate reacts slowly to form an alkyl nitrite and a nitro compound:



With strongly basic nucleophiles the addition to the triple bond takes place at a much higher rate than the alkylation reaction so that in most cases only the compound formed by the latter reaction could be isolated. Thus, alkyl cyanates react with aqueous sodium sulfide to form thiocarbamates and not even traces of alkyl sulfides or thiols could be detected. Similarly thiols, phenols and alcoholate ions add to the triple bond without simultaneous formation of alkylation products.

Cyanide ions also add to the triple bond to form an unstable compound which subsequently forms cyanogen (see a following paper³²):



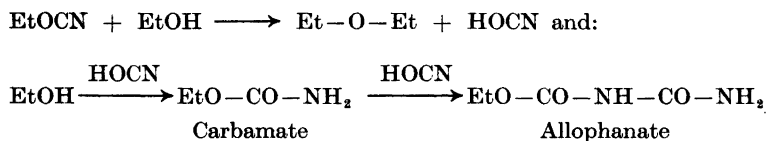
No alkyl cyanide or isocyanide could be detected.

Whereas thiocyanate ions are alkylated by alkyl cyanates in aqueous solution, free thiocyanic acid adds to the triple bond of an alkyl cyanate in a non-aqueous medium with the formation of a compound of empirical composition $\text{ROCN} \cdot 2\text{HSCN}$. The constitution of these compounds is under investigation.

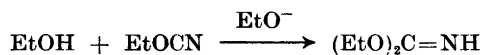
The addition reactions of S^{2-} , CN^- and N_3^- may actually proceed *via* unionized H_2S , HCN , and HN_3 , formed by hydrolysis, and, in fact, these compounds add to alkyl cyanates in ethereal solution. These reactions are, however, strongly catalyzed by basic reagents so that it seems plausible that the reactions proceed also in these cases *via* the anions.

6. The reaction of alkyl cyanates with alcohols, phenols and their thio analogues

In contrast to aryl cyanates, alkyl cyanates react with alcohols in neutral medium, although the reaction is strongly catalyzed by acids or bases. When a solution of ethyl cyanate in ethanol was kept for 12 h at 35°C, the cyanate was completely transformed, depending upon the concentration, either into ethyl carbamate, which remained in solution, or into allophanate which precipitated from the solution. A gas evolution was observed and was first assumed to be due to the formation of ethylene by elimination of cyanic acid from ethyl cyanate. However, infrared spectroscopy of the gas, isolated by cooling with liquid air, proved the compound to be diethyl ether and not even traces of ethylene could be detected. Gas chromatographic examination of the reaction products confirmed this result. The reaction may thus be formulated as the result of an alkylating effect of the alkyl cyanate:



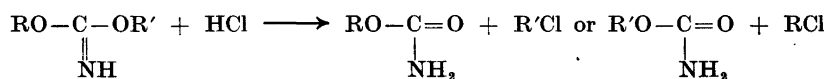
With sodium ethanolate the reaction takes another course, diethyl imido carbonate being formed:



This reaction explains why earlier attempts to prepare alkyl cyanates by the reaction between sodium ethanolate and cyanogen bromide have been unsuccessful. Hantzsch and Mai³³ reported a nearly quantitative formation of diethyl imidocarbonate. Other investigators, however, in addition to diethyl imidocarbonate have found trialkyl cyanurate as a product of this reaction, and the formation of the latter compound has been interpreted as an indication that ethyl cyanate would be unstable because of easy polymerisation to triethyl cyanurate. Our earlier experiments^{1,3} show, however, that ethyl cyanate does not polymerise directly to triethyl cyanurate but first isomerises to ethyl isocyanate which then polymerises to triethyl isocyanurate. According to Houben,³⁴ impure diethyl imidocarbonate, when distilled at normal pressure, partly decomposes with the formation of triethyl cyanurate and this is obviously the reason for the recorded formation of trialkyl cyanurate in this reaction. In our experiments the reaction of ethyl cyanate and sodium ethanolate in ethanol yielded diethyl imidocarbonate as the only reaction product.

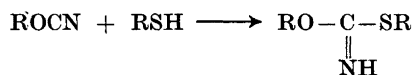
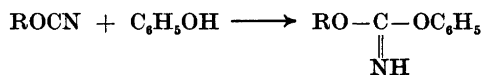
The alkyl cyanates may be transformed into trialkyl cyanurates *via* the imidocarbonates, but this is a ring formation *via* condensation and not a polymerisation. Our experiments definitely show that alkyl cyanates — apparently in contrast to the aryl cyanates⁸ — do not polymerise to cyanurates but first isomerise to isocyanates which then polymerise to isocyanurates.

The acid-catalyzed reaction between alkyl cyanates and alcohols results in the formation of alkyl carbamates. However, the carbamate formed corresponds to the alcohol used and not to the alkyl cyanate. Thus, ethyl cyanate and propyl alcohol form propyl carbamate, and propyl cyanate and isopropyl alcohol form isopropyl carbamate. This is readily explained by assuming that the alkyl cyanate first reacts with hydrogen chloride to form alkyl chloride and cyanic acid which then reacts with the alcohol used as solvent. The transient formation of cyanic acid is testified by the appearance of some cyamelide hydrochloride or cyanuric acid as by-products in most of the experiments. There was also the possibility that the alkyl cyanate had reacted with the alcohol to form an imidocarbonate, since imidocarbonates are unstable towards hydrogen chloride, which transform them into carbamates (or cyanates) with the formation of an alkyl chloride:



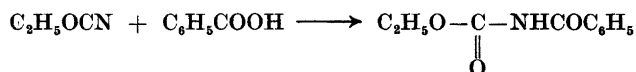
However, if this reaction were a predominant one, both carbamates would be expected to be formed in comparable yields.

With phenol, thiophenol, or butanethiol imidocarbonates, and thioimidocarbonates were formed (no alkylation reactions were observed):



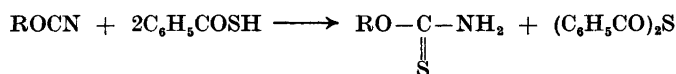
7. Reactions of alkyl cyanates with carboxylic and thiocarboxylic acids

Ethyl cyanate reacted with benzoic acid to form *N*-benzoyl *O*-ethyl carbamate:



However, with acetic acid ethyl carbamate and acetic anhydride were formed. The latter type of reaction seems to be general for aryl cyanates since Grigat *et al.*²⁶ and Martin *et al.*¹⁹ were unable to isolate any *N*-acylurethans in these reactions.

Thiobenzoic acid reacted in a similar way as acetic acid forming thio-carbamates and dibenzoyl sulfide:



Unlike the reaction between an alkyl cyanate and benzoic acid, or between an alkyl thiocyanate and thiobenzoic acid,³⁵ the reaction between an alkyl cyanate and thiobenzoic acid does not yield an *N*-benzoyl derivative, although this may be formed as an intermediate.

8. Behaviour of alkyl cyanates towards oxidizing and reducing agents

Alkyl cyanates are very resistant toward oxidants; for example, isobutyl cyanate was practically unchanged after treatment with bromine in CCl_4 -solution for a week.

However, alkyl cyanates react with hydrogen peroxide, but the reaction products have not yet been identified.

Treatment of alkyl cyanates with reducing agents is usually complicated by isomerisation or hydrolysis. Diborane reduces ethyl cyanate to ethanol, formaldehyde and ammonia; the possible intermediate, ethyl formate, could not be detected by gas chromatography.

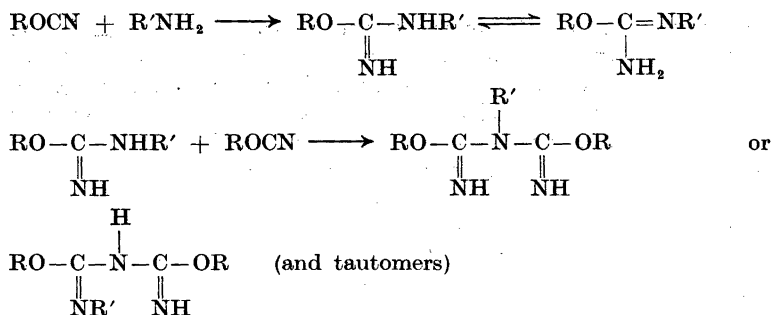
Grignard reactions of alkyl cyanates will be treated in a subsequent paper. They proceed in a much more complicated way than the Grignard reactions of aryl cyanates, studied by Martin *et al.*²⁰ and Grigat *et al.*²⁸

9. The reaction of alkyl cyanates with amines

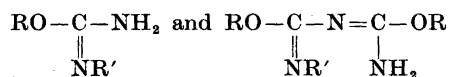
In our first paper on alkyl cyanates¹ we reported that ethyl cyanate reacted with aniline to form phenylurea. Also propyl, isopropyl, and butyl cyanate have been found to yield phenylurea in the reaction with aniline. None of the expected *O*-alkyl-*N*-phenyl-isoureas could be detected. The phenylurea could conceivably have been formed by hydrolysis of the isoureas but this seemed rather unlikely because water was rigorously excluded in the experiments. It has now been found that the formation of phenylurea is due to the alkylating action of alkyl cyanates: they react rapidly with aniline to form *N*-alkylanilines and cyanic acid which in turn reacts with excess aniline to form phenylurea. Both *N*-ethylaniline and *N,N*-diethylaniline were identified by gas chromatography as products of the reaction between ethyl cyanate and aniline; in addition to phenylurea, some *N*-phenyl-*N*-ethylurea, formed from cyanic acid and *N*-ethylaniline, could also be isolated from the reaction mixture. *N*-Ethylaniline was found to react with ethyl cyanate with the formation of *N*-ethyl-*N*-phenylurea and, at the same time, *N,N*-diethylaniline was formed.

In these reactions the alkyl cyanates differ fundamentally from the aryl cyanates.

Among the primary aliphatic amines only *tert*-butylamine has been found to react in part in a similar way as aniline, forming *tert*-butylurea. With other aliphatic amines, and also with ammonia, only addition to the triple bond occurs. The primary product of this reaction is an *O*-alkylisourea which may react with another molecule of the cyanate to form an *O,O'*-dialkylisobiuret (*O,O*-dialkyl imino-bis(imidoformate)):



Ammonia reacts with two moles of the alkyl cyanate, even when ammonia is present in large excess. With propylamine and butylamine both types of compounds are formed depending upon the ratio between the alkyl cyanate and the amine. Grigat and Pütter¹¹ have obtained similar results with aryl cyanates. However, these authors ascribe the iminobis(imidoformates) the symmetrical formula, but it is not certain that this is correct. It might well be that both symmetrical and unsymmetrical molecules may be formed, depending upon the steric and electronic nature of the radical R', so this question evidently needs further study. The problem is complicated by the possible existence of three tautomeric forms of the unsymmetrical compound. The isoureas and isobiurets prepared in our experiments all exhibit a strong NH₂-deformation band in their infrared spectra and therefore — at any rate predominantly — consist of the tautomeric forms of the isoureas and the *unsymmetrical* biurets which contains an amino group:

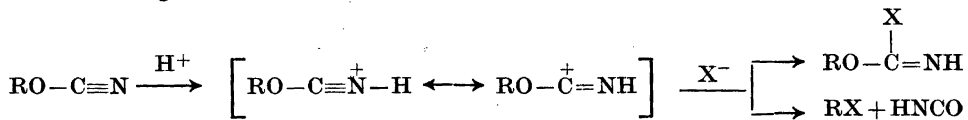


DISCUSSION

Although kinetic and other physico-chemical measurements will be necessary to completely clarify the chemical reactions of alkyl cyanates, the following generalisations seem to be warranted on the basis of our qualitative observations:

(1) The addition reactions are strongly catalyzed both by acids and bases. For example, the uncatalyzed reaction with water is very slow and because of simultaneous isomerisation and polymerisation of the cyanate it is usually not possible to isolate a carbamate. On addition of hydrochloric acid or sodium hydroxide, water is added rapidly and the carbamate is formed in good yield.

(2) The alkylation reactions are also catalyzed by acids; both the acid catalyzed addition and alkylation reactions might be assumed to proceed *via* the following intermediate ion:



However, the striking difference between alkyl cyanates and aryl cyanates, especially the polymerisation to isocyanurates in one case and to cyanurates in the other, might be due to the O-atom being more basic than the N-atom when it is attached to alkyl and less so when it is attached to aryl. Thus, proton acids (and also Lewis acids) might attack the oxygen atom in the case of alkyl cyanates, but the nitrogen atom in the case of aryl cyanates. This question evidently needs further study.

The observation that isopropyl chloride and *tert*-butyl chloride are not formed in the reactions of propyl cyanate and isobutyl cyanate, respectively, with hydrogen chloride suggests that these reactions proceed by an S_N2 mechanism and not as carbonium ion reactions. A closer investigation of the reaction mechanism using optically active alkyl cyanates is in progress.

(3) General base catalysis of the addition reactions is demonstrated, for example, by the effect of pyridine on the addition of hydrogen sulfide to alkyl cyanates. The higher cyanates, *e.g.* isobutyl cyanate, add hydrogen sulfide extremely slowly, but on addition of pyridine the reaction proceeds smoothly. This is presumably due to partial transformation of H_2S into the more nucleophilic HS^- ions, under the influence of a complex with pyridine bound to the alkyl cyanate (the formation of such a complex seems plausible since pyridine also catalyses the polymerisation of cyanates).

However, strongly basic anions behave not as catalysts but irreversibly add to the cyanate. Thus, for example, the hydroxide ion, added directly or formed as a result of hydrolysis of salts of weak acids, is not a catalyst in aqueous solution because it is added irreversibly with the formation of carbamate. Accordingly, a carbamate is often observed as a by-product in the reactions of alkyl cyanates with nucleophilic anions, *e.g.* CN^- and N_3^- , in aqueous solution.

It should here be remembered that it is only the nucleophilicity towards nucleophilic addition reactions which runs parallel with the base strength. The case of I^- and SH^- is typical: both ions are powerful nucleophiles in nucleophilic substitution reactions, but the former, which is a very weak base, is inactive in nucleophilic addition reactions. Since the nucleophilic addition reactions proceed at a much higher rate than the substitution reactions — which is evident, for example, from the fact that HS^- is added without the formation of even a trace of a thiol — substitution reactions (alkylations) are only to be expected with anions which are weak bases, such as I^- , SCN^- , NO_2^- , and N_3^- and this was actually also found to be the case. In contrast to the azide ion, free HN_3 is added to the triple bond, probably because of acid catalysis of the addition reaction.

Further, weakly basic neutral nucleophiles are alkylated: Ethanol is transformed into diethyl ether by ethyl cyanate, whereas the ethoxide adds to the triple bond. Aniline is alkylated, whereas aliphatic amines generally are added to the triple bond. The only exception found was *tert*-butyl amine which formed both an alkylation and an addition product; this may be explained by steric hindrance which slows down the speed of the addition reaction so that the competing alkylation reaction may manifest itself. In contrast to alcohols, phenols and thiols are not alkylated, presumably because they ionize sufficiently to the strongly nucleophilic anions to make the addition reaction predominant and at the same time function as acid catalysts for this reaction.

EXPERIMENTAL

Alkyl cyanates were prepared as described in our earlier publication.³

Reaction of alkyl cyanates with aqueous acids
and bases

a) To an ice-cooled solution of 0.50 g of ethyl cyanate in ether was added with shaking 2 ml of conc. 10 M aqueous sodium hydroxide. After a few minutes the ether solution was separated and the aqueous solution extracted with ether. The combined ether extracts were dried and evaporated. Yield 0.60 g (96 %) of ethyl carbamate.

b) To an ice-cooled solution of 0.50 g of propyl cyanate in ether (2 ml) was added with shaking 2 ml of conc. hydrochloric acid. A precipitate of cyamelide hydrochloride (0.04 g) separated at once. From the ether solution was isolated propyl carbamate (0.30 g) and propyl chloride (0.17 g). The identity of the latter was proved by gas chromatography with addition of propyl chloride and isopropyl chloride, respectively. The identity of the two first mentioned products was proved by analyses and IR spectra. Total yield 95 %.

c) Isobutyl cyanate adds water to form isobutyl carbamate in 50 % yield on being passed through a moist Al_2O_3 column or being shaken in an ethereal solution with moist aluminium oxide. This was found to be the case both with acid and neutral aluminium oxide, but by application of dehydrated aluminium oxide no ether-soluble products were formed, indicating that the cyanate had been polymerised.

Similar results were obtained with other alkyl cyanates.

Alkyl cyanates and hydrogen selenide

Hydrogen selenide was led into an ice-cooled solution of 0.01–0.04 mole of the alkyl cyanate in dry ether (30 ml) for about 1 h. The solution was filtered from some selenium which had separated and evaporated *in vacuo*. The residue was usually crystalline and was recrystallised from petroleum ether, after which the selenocarbamates were obtained as colourless crystals. The butyl derivative was only obtained as an oil. Melting points and analyses are given below. The ethyl derivative had been prepared earlier in another way² and was identified by its infrared spectrum.

When the solution was evaporated before the calculated amount of hydrogen selenide had been absorbed, so that the cyanate was present in excess, the residues were oily also in the case of ethyl and propyl derivative, but on addition of pentane colourless crystals were obtained. These compounds have the composition corresponding to addition of two moles of the cyanate to one mole of hydrogen selenide but are very unstable so it has not been possible to get quite satisfactory analyses:

Table 1. O-Alkyl selenocarbamates (selenourethans), $\text{RO}-\text{CSe}-\text{NH}_2$.

R	Yield, %	M.p., °C	Formula	Analyses				
				C	H	N	Se	
Ethyl ²	78	44.5–45	$\text{C}_3\text{H}_7\text{ONSe}$					
Propyl	86	32.5–33	$\text{C}_4\text{H}_9\text{ONSe}$	calc.:	28.90	5.47	8.44	47.60
				found:	29.15	5.45	8.31	47.70
Isopropyl	72	90–90.5	$\text{C}_4\text{H}_9\text{ONSe}$	found:	28.92	5.38	8.24	
Butyl	82	oil	$\text{C}_5\text{H}_{11}\text{ONSe}$	calc.:	33.60	6.14	7.78	43.70
				found:	33.53	6.06	7.89	43.52
Isobutyl	74	63–63.5	$\text{C}_5\text{H}_{11}\text{ONSe}$	found:	33.68	6.28	7.65	43.93
sec-Butyl	84	59–60	$\text{C}_5\text{H}_{11}\text{ONSe}$	found:	33.82	6.02	7.58	43.52

Bis(ethoxycarbonimidoyl)selenide, m.p. 129–131°C, yield 1.29 g from 0.83 g of ethyl cyanate (70 %). (Found: C 33.17; H 4.98; Se 31.23. Calc. for $C_6H_{12}N_2O_2Se$: C 32.30; H 5.42; Se 35.39).

Reactions of alkyl cyanates with dry hydrogen chloride

Several experiments were carried out in which dry hydrogen chloride was led into a solution of an alkyl cyanate (ethyl, propyl, isopropyl, isobutyl) in an inert solvent (hexane, carbon tetrachloride, diethyl ether), either at -80°C or at room temperature (with or without removal of the reaction heat). In all cases a white solid separated immediately; this was shown by analyses and infrared spectra to be cyamelide hydrochloride when the reaction was carried out at low temperature and cyanuric acid when the reaction was carried out above room temperature. When the reaction was carried out at room temperature much cyanic acid escaped from the solvent and was collected, together with other volatile reaction products, in a cooled trap where it rapidly polymerised to cyamelide hydrochloride or cyanuric acid. The alkyl chlorides present in the solution or in the trap were analysed by gas chromatography and infrared spectroscopy. From the solution a few percent of alkyl carbamates or alkyl allophanates (identified by their melting points and infrared spectra) could usually be isolated. The following is a typical experiment:

Hydrogen chloride was led through a solution of propyl cyanate (1 g) in hexane (15 ml) for 15 min at 23°C and passed to a trap cooled at -80°C . Yield: 0.43 g of cyanuric acid (85 %), and 50 mg of propyl carbamate (8 %) and 0.40 g of propyl chloride, b.p. $46-47^\circ\text{C}$ (43 %). No isopropyl chloride could be detected by gas chromatography.

Reactions of alkyl cyanates with nucleophilic anions in aqueous solutions

a) Isobutyl cyanate (0.1 g) was shaken with a solution of 3 g of potassium iodide in 6 ml of water for 10 min. The supernatant was separated and shown by gas chromatography to consist of isobutyl iodide and unchanged isobutyl cyanate.

b) A solution of ethyl cyanate (0.5 g) in diethyl ether (10 ml) was added with shaking to a solution of 10 g of potassium cyanate in 20 ml of water. Gas chromatographic analysis showed that 70 % of the cyanate had been transformed into the isocyanate.

c) A solution of ethyl cyanate (0.5 g) in diethyl ether (10 ml) was added with shaking to a solution of 10 g potassium thiocyanate in 20 ml of water. The ether layer was separated and the aqueous solution extracted with ether. The combined ether solutions were dried with sodium sulfate and the solvent removed by evaporation at 0°C . The liquid residue (0.50 g, 82 %) was shown by mass spectrometry and its infrared spectrum to be ethyl thiocyanate.

d) A solution of isobutyl cyanate (0.4 g) in diethyl ether (1 ml) was shaken with a solution of 5 g of sodium azide in 15 ml of water for 5 min. Gas chromatography of the ether solution showed that all cyanate had disappeared and been replaced by a low-boiling component. This was isolated and identified by its infrared spectrum as isobutyl azide. The ether solution left on evaporation 70 mg (15 %) of a solid which was identified by means of its infrared spectrum as isobutyl carbamate. No alkoxytetrazole was formed under these conditions. However, in acid solution alkoxytetrazoles are formed instead of alkyl azides: A solution of isobutyl cyanate (0.485 g) in diethyl ether (5 ml) was shaken with 20 ml of a 0.864 N aqueous solution of hydrogen azide. The ether layer was separated and the solution extracted with ether. The combined and dried ether layers left on evaporation 5-isobutyloxytetrazole (0.419 g; 60 %) as a colourless solid. M.p. $107-108^\circ\text{C}$ after recrystallisation from benzene. (Found: C 41.92; H 6.66; N 38.96. Calc. for $C_5H_{10}N_4O$: C 42.24; H 7.09; N 39.41). Other 5-alkoxytetrazoles will be described in another paper.

e) Isobutyl cyanate (0.4 g) was shaken with a solution of 2.5 g of sodium nitrite in 5 ml of water for $\frac{1}{2}$ h. The gas chromatogram showed in addition to a few percent

unchanged cyanate two peaks corresponding to isobutyl nitrite (23 %) and 2-methyl-2-nitropropane (77 %). The two compounds were collected and identified by comparison of their infrared spectra with the spectra of authentic samples, prepared, respectively, from isobutyl alcohol and nitrous acid and from α -bromoisovaleric acid and sodium nitrite (the nitro compound prepared from isobutyl iodide and silver nitrite was found to be rather impure).

f) A solution of isobutyl cyanate (0.394 g) in diethyl ether (5 ml) was shaken with a solution of 3 g of sodium sulfide in 10 ml of water for $\frac{1}{2}$ h. The ether layer was separated and the aqueous solution extracted with ether. Gas chromatographic analysis of the combined ether layers showed that no diisobutyl sulfide had been formed. The ether layer left on evaporation 0.454 g (86 %) of an oil which crystallised on cooling. According to its m.p. (50–51°C, after recrystallisation from water) and infrared spectrum it was *O*-isobutyl thiocarbamate. The aqueous layer was made acid and extracted with ether; gas chromatographic analysis showed that no 2-methyl-1-propanethiol had been formed. The aqueous solution did not give a positive reaction for thiocyanate.

Alkyl cyanates and alcohols

Formation of diethyl ether. In a small two-necked flask was placed a solution of 1 g of ethyl cyanate in 5 ml of ethanol. During 24 h a slow stream of helium was swept through the system in order to remove a volatile compound which was formed; this was trapped in a system cooled with liquid air and analysed by infrared spectroscopy in a glass cell. The spectrum was identical with that of diethyl ether, and no trace of ethylene was observed. The yield of diethyl ether was almost quantitative. From the ethanol solution, ethyl allophanate (identified by m.p., 191–192°C, and infrared spectrum) was isolated in a 90 % yield.

In another experiment the reaction was carried out in a closed vessel and the product analysed directly by gas chromatography. Again, a quantitative conversion of ethyl cyanate into diethyl ether was found.

The base-catalyzed reaction. A 2 N ethanolic solution of C_2H_5ONa (2 ml) was dropped into an ice-cooled solution of ethyl cyanate (1 g) in ether (3 ml). After removal of the solvents a liquid distilled at 35–37°C and 10 mm Hg. According to analyses as well as infrared and ultraviolet ³⁶ spectra, it was identified as diethyl imidocarbonate, $(C_2H_5O)_2C=NH$. Yield 0.93 g (56 %).

The acid-catalyzed reaction. a) Dry hydrogen chloride was led through a solution of isopropyl cyanate (0.30 g) in propanol (6 ml) at 20°C for 15 min. On evaporation of the solution a crystalline mass was obtained, which was identified as *propyl carbamate* by its melting point (55°C, recryst. from ether). Yield 0.36 g (99 %). In an analogous experiment with isopropyl alcohol as solvent, 0.36 g of *isopropyl carbamate* (m.p. 92–93°C, after sublimation) was obtained. With ethanol as solvent some cyamelide hydrochloride was formed and the yield of ethyl carbamate was only 63 %.

Similar results have been obtained with other alkyl cyanates and alcohols. In some experiments small amounts of the alkyl allophanate were obtained in addition to the alkyl carbamate.

b) A solution of ethyl cyanate (358 mg) and acetic acid (300 mg) in ethanol (4 ml) was kept for 14 h at room temperature. A crystalline colourless compound, which had separated, was identified by m.p. (191–192°C), analyses and infrared spectrum as ethyl allophanate. Somewhat more of the same compound (total yield 138 mg, 42 %) and in addition 80 mg of ethyl carbamate (18 %) were obtained from the solution.

Ethyl cyanate and phenol

Solutions of ethyl cyanate (0.71 g) and phenol (0.94 g), each in 5 ml of diethyl ether, were mixed and kept for 24 h. On removal of the ether an oily liquid was obtained (1.55 g; 94 %) the analyses of which corresponded to ethyl phenyl imidocarbonate, $(C_2H_5O)(C_6H_5O)C=NH$. (Found: C 65.80; H 7.13; N 8.34. Calc. for $C_9H_{11}NO_2$: C 65.49; H 6.70; N 8.48). The compound has been obtained earlier by Nef.³⁷ It decomposes into phenol, ethanol, and phenyl cyanurate on attempts at distillation.

Alkyl cyanates and thiols

O-Ethyl-S-butyl-imidothiocarbonate, $C_2H_5O-C(=NH)-SCH_2CH_2CH_2CH_3$. 1-Butanethiol (1.80 g) was added to a solution of ethyl cyanate (0.71 g) in 5 ml of dry ether. Reaction occurred immediately with heat evolution. The reaction mixture was kept at 30°C for about 20 h and the ether and excess butanethiol were removed by means of an oil pump, the flask being kept at 45°C. The residue (1.55 g; 97 %) was an oil which could not be distilled without decomposition; the analyses, however, correspond well to the expected composition. (Found: C 52.25; H 9.31; N 8.55; S 19.90. Calc. for $C_7H_{15}ONS$: C 52.10; H 9.39; N 8.68; S 19.93).

Characteristic infrared bands (in CCl_4): 3300 w (NH), 1615 s (C=N), 1260 s, 1225 s, 1157 vs ($O-C_2H_5$), 860 m.

O-Ethyl-S-phenyl-imidothiocarbonate, $C_2H_5O-C(=NH)-SC_6H_5$. This compound was prepared as above, but there was no heat evolution on mixing the components. The product was an oil. Yield 1.79 g = 99 %. (Found: C 60.10; H 6.10; N 7.59; S 18.64. Calc. for $C_8H_{11}ONS$: C 59.65; H 6.11; N 7.74; S 17.70). The hydrochloride, m.p. 72–74°C, was also prepared by Knorr³⁸ from phenyl thiocyanate, ethanol, and hydrogen chloride; on melting it decomposes into ethyl chloride and *S*-phenyl thiocarbamate.

Characteristic infrared bands (in CCl_4): 3300 m (NH), 1640 s (C=N), 1260 vs, 1225 s, 1160 vs ($O-C_2H_5$), 860 m.

Alkyl cyanates and carboxylic acids

a) A solution of ethyl cyanate (0.36 g) in ether (5 ml) was added to an ice-cold solution of benzoic acid (0.61 g) in ether (10 ml) and the mixture kept for 24 h. On evaporation 0.86 g (89 %) of colourless crystals with m.p. 108–110°C (109–110°C, after recrystallisation from ethanol-water) were obtained. The m.p. and infrared spectrum proved identical with those of authentic *O*-ethyl *N*-benzoylcarbamate, prepared from urethan and benzoyl chloride.³⁹

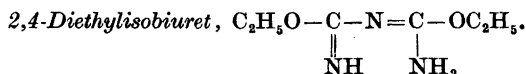
b) Isobutyl cyanate (0.326 g) and acetic acid (0.200 g), each dissolved in 5 ml of hexane, were mixed. No reaction had taken place after 12 h, therefore one drop of triethylamine was added. After 42 h the volatile compounds were removed by evaporation *in vacuo* at 0.1 mm Hg. The residue solidified on cooling and was recrystallised twice from hexane. According to its m.p., 61–62°C (lit.^{40,41} 61° and 63°) and analysis, the compound was isobutyl carbamate.

Alkyl cyanates and thiobenzoic acid

A solution of thiobenzoic acid (1.73 g) in ether (10 ml) was added to an ice-cold solution of isopropyl cyanate (1.07 g) in ether (10 ml). After 24 h a trace of a white solid had separated; it was filtered and shown to be cyanuric acid. The filtrate left on evaporation a mixture of crystals and an oil (2.60 g) from which *O*-isopropyl thiocarbamate (m.p. 80–81°C) was isolated by crystallisation from pentane-chloroform. The solution left after removal of the solvents a residue which, after recrystallisation three times from ether, yielded dibenzoyl sulfide, m.p. 47–48°C. The infrared spectra of the two compounds were identical with the infrared spectra of authentic samples of *O*-isopropyl thiocarbamate and dibenzoyl sulfide, respectively.

Other alkyl cyanates reacted in a similar way, but it proved difficult to separate completely the thiocarbamates from the dibenzoyl sulfide.

Alkyl cyanates and ammonia or amines



A solution of 5 ml of liquid ammonia in ether was added slowly to a solution of 1 g of ethyl cyanate in ether (5 ml). Reaction took place with heat evolution. After standing for ca. 20 h the ether was removed *in vacuo*. The residue was a light yellow oil which could not be distilled without decomposition. Yield 1.02 g (91 %). (Found: C 45.13; H 7.97; N 26.31. Calc. for $C_6H_{13}O_2N_3$: C 45.25; H 8.24; N 26.41). The infrared spectrum exhibits a strong NH_2 -band at 1638 cm^{-1} .

The name "isobiurets" has been chosen because it covers both tautomeric forms, $RO-C(=NH)-NH-C(=NH)-OR$ and $RO-C(=NH)-N=C(NH_2)-OR$, whereas only the first one can properly be called an iminobis(imidoformate).

O-Ethyl-N-propylisourea, $C_2H_5O-C(NH_2)=NC_3H_7$. Ethyl cyanate (0.82 g) and propylamine (1.36 g, 2 moles), each dissolved in ether (5 ml), were mixed. Reaction occurred with heat evolution. After standing overnight, the ether and excess amine were removed *in vacuo*. The remaining colourless oil was purified by being dissolved in hexane, cooled in "dry ice"-acetone, and the precipitated oil collected and pumped free of volatile impurities under vacuum. Yield 93 %. (Found: C 55.15; H 10.63; N 21.80. Calc. for $C_6H_{14}N_2O$: C 55.35; H 10.84; N 21.52). The infrared spectrum exhibits a strong NH_2 -band at 1640 cm^{-1} and a weaker $C=N$ band at 1680 cm^{-1} .

O-Ethyl-N-butylisourea was prepared in the same manner and showed similar properties. Yield 91 %. (Found: C 58.30; H 11.18; N 19.25. Calc. for $C_7H_{16}N_2O$: C 58.30; H 11.18; N 19.43).

1-Propyl-2,4-diethylisobiuret, $C_3H_7N=C(OC_2H_5)-N=C(OC_2H_5)NH_2$. This substance was prepared in a similar manner as the isourea but with two moles of the cyanate to one mole of the amine. Yield 99 %. (Found: C 54.05; H 9.45. Calc. for $C_9H_{19}N_3O_2$: C 53.70; H 9.52). The compound has similar properties to the isourea and shows a strong NH_2 band in its infrared spectrum at 1640 cm^{-1} ; a characteristic difference from the infrared spectrum of the isourea is a strong band at 1595 cm^{-1} , which may be due to the $C=N$ stretching vibration, lowered by conjugation.

1,2,4-Tripropylisobiuret was prepared in the same manner using propyl cyanate and propyl amine. Yield 99 %. (Found: C 57.85; H 10.27. Calc. for $C_{11}H_{23}N_3O_2$: C 57.61; H 10.11).

tert-Butylamine and ethyl cyanate yielded 1-*tert*-butyl-2,4-diethylisobiuret even with excess amine but in addition *tert*-butylurea was formed. Yield of the isobiuret 58 %. (Found: C 56.10; H 10.23; N 20.05. Calc. for $C_{10}H_{21}N_3O_2$: C 55.80; H 9.84; N 19.55). Yield of *tert*-butylurea 31 %; m.p. $180-182^\circ\text{C}$, infrared spectrum identical with that of an authentic sample of *tert*-butylurea, prepared from *tert*-butyl isocyanate and ammonia.

The reaction of ethyl cyanate with aniline

A solution of 0.71 g of ethyl cyanate (0.01 mole) in 3 ml of ether was added to a solution of 1.90 g (0.02 mole) of aniline in 3 ml of ether and the mixture kept for 24 h in a closed vessel. The ether was removed by evaporation and the residue was steam-distilled. The distillate was extracted with ether and the amines were separated and determined quantitatively by gas chromatography. The amounts of aniline, ethylaniline and diethylaniline in weight-percentages were found to be 31, 53 and 16 %, respectively. The total amount of amines was 1.33 g, representing a recovery of 57 % of the aniline used.

The residue from the steam distillation was extracted three times with ether-hexane 1:1 and 0.946 g of phenylurea was left as a crystalline residue. M.p. 147°C ; the infrared spectrum was identical with that of an authentic sample of phenylurea. The solution left, on evaporation, 0.245 g of an oil which solidified on standing and, on recrystallization from hexane, yielded pure *N*-ethyl-*N*-phenylurea with m.p. $62-62.5^\circ\text{C}$. The infrared spectrum was identical with that of an authentic sample of *N*-ethyl-*N*-phenylurea. The amounts of *N*-phenylurea and *N*-ethyl-*N*-phenylurea isolated correspond to 0.00697 and 0.00150 mole, respectively, thus representing a conversion of 85 % of the ethyl cyanate and 42.5 % of the aniline used.

In a similar experiment, with 0.02 mole of ethylaniline and 0.01 mole of ethyl cyanate, 1.806 g of an oil, consisting of 63 % diethylaniline and 37 % ethylaniline, was obtained

together with 1.25 g of *N*-ethyl-*N*-phenylurea, representing a 77 % conversion according to the equation: $C_6H_5OCN + 2C_6H_5NHC_2H_5 \rightarrow C_6H_5(C_2H_5)_2N + C_6H_5(C_2H_5)N-CO-NH_2$. Propyl cyanate, isopropyl cyanate and butyl cyanate have similarly been converted to phenylurea by aniline in 50–70 % yields.

REFERENCES

1. Jensen, K. A. and Holm, A. *Acta Chem. Scand.* **18** (1964) 826.
2. Jensen, K. A. and Holm, A. *Ibid.* **18** (1964) 2417.
3. Jensen, K. A., Due, M. and Holm, A. *Ibid.* **19** (1965) 438.
4. Groving, N. and Holm, A. *Ibid.* **19** (1965) 443.
5. Groving, N. and Holm, A. *Ibid.* **19** (1965) 1768.
6. Martin, D. *Angew. Chem.* **76** (1964) 303.
7. Martin, D. *Chem. Ber.* **97** (1964) 2689.
8. Grigat, E. and Pütter, R. *Chem. Ber.* **97** (1964) 3012.
9. Grigat, E. and Pütter, R. *Chem. Ber.* **97** (1965) 3018.
10. Grigat, E. and Pütter, R. *Chem. Ber.* **97** (1965) 3022.
11. Grigat, E. and Pütter, R. *Chem. Ber.* **97** (1965) 3027.
12. Stroh, R. and Gerber, H. *Angew. Chem.* **72** (1960) 1000.
13. Hedayateullah, M. and Denivelle, L. *Compt. Rend.* **256** (1963) 4029.
14. Martin, D. *Tetrahedron Letters* **1964** No. 39, p. 2829.
15. Kauer, J. C. and Henderson, W. W. *J. Am. Chem. Soc.* **86** (1964) 4732.
16. Martin, D., Herrmann, H. J., Rackow, S. and Nadolski, K. *Angew. Chem.* **77** (1965) 96.
17. Martin, D. and Mucke, W. *Chem. Ber.* **98** (1965) 2059.
18. Reich, P. and Martin, D. *Chem. Ber.* **98** (1965) 2063.
19. Martin, D. *Chem. Ber.* **98** (1965) 3286.
20. Martin, D. and Rackow, S. *Chem. Ber.* **98** (1965) 3662.
21. Grigat, E. and Pütter, R. *Angew. Chem.* **77** (1965) 452.
22. Grigat, E., Pütter, R., Schneider, K. and Wedemeyer, K. F. *Chem. Ber.* **97** (1964) 3036.
23. Grigat, E. and Pütter, R. *Chem. Ber.* **97** (1964) 3560.
24. Grigat, E., Pütter, R. and König, C. *Chem. Ber.* **98** (1965) 144.
25. Grigat, E. and Pütter, R. *Chem. Ber.* **98** (1965) 1168.
26. Grigat, E. and Pütter, R. *Chem. Ber.* **98** (1965) 1359.
27. Grigat, E. and Pütter, R. *Chem. Ber.* **98** (1965) 2619.
28. Grigat, E., Pütter, R. and Mühlbauer, E. *Chem. Ber.* **98** (1965) 3777.
29. Jensen, K. A. and Pedersen, C. *Advan. Heterocyclic Chem.* **3** (1964) 277.
30. Werner, A. E. A. and Gray, J. *Sci. Proc. Roy. Dublin Soc.* **24** (1947) 209.
31. Gould, E. S. *Mechanism and Structure in Organic Chemistry*, Holt, Rinehart and Winston, New York 1959, p. 298.
32. Wentrup, C. *Acta Chem. Scand.* **20** (1966) 2128.
33. Hantzsch, A. and Mai, L. *Ber.* **28** (1895) 2466.
34. Houben, J. and Schmidt, E. *Ber.* **46** (1913) 2447; Houben, J. and Zivadinovitsch, R. *Ber.* **69** (1936) 2352.
35. Wheeler, H. L. and Merriam, H. F. *J. Am. Chem. Soc.* **23** (1901) 283.
36. Schurz, J., Treiber, E. and Toplak, H. *Z. Elektrochem.* **60** (1956) 67.
37. Nef, J. U. *Ann.* **287** (1895) 265, p. 321.
38. Knorr, A. *Ber.* **49** (1916) 1735, p. 1738.
39. Pechmann, H. V. and Vanino, L. *Ber.* **28** (1895) 2383.
40. Thiele, J. and Dent, F. *Ann.* **302** (1898) 245, p. 271.
41. Wagner, J. *Z. physik. Chem.* **B 43** (1939) 333, p. 337.

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