[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF JOHNS HOPKINS UNIVERSITY.]

STUDIES IN THE PREPARATION OF NITRILES. II. THE PREPARATION OF ALIPHATIC NITRILES.

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Introduction.'

For the preparation of nitriles we have had the old method of Letts[1] as improved by Krüss,[2] which was to heat an acid, such as benzoic acid, with lead thiocyanate. This method was easy to carry out and gave fair yields. Several years ago,[3] in this laboratory, this method was studied and it was found that far better yields could be obtained by substituting the zinc salt of the acid for the free acid, but only aromatic acids were experimented with. The present work was taken up to test the applicability of this improved method to aliphatic nitriles and to find the best conditions for their preparation.

The preparation of acetonitrile has been studied most extensively on account of the importance and the availability of acetic acid. Various methods of heating have been experimented with. Zinc salts of acetic, propionic, butyric, isovaleric, stearic, phenylacetic, phenylpropionic, cinnamic, and terephthalic acids, and the lead salts of some of these acids, have been heated with lead thiocyanate. Several other thiocyanates have been used and the results compared with those obtained with the lead salt. Calcium, copper, stannous, manganous, nickel, cobalt, magnesium, strontium, barium and basic ferric acetates have been tried.

Historical.

E. A. Letts[4] of London, in 1872, studied the action of potassium thiocyanate on acids. In case of acetic acid, he could not obtain the nitrile, but with isobutyric acid and valeric acid he found both amide and nitrile, the amide being the main product. With benzoic acid the nitrile was almost the sole product, only traces of the amide being found.

Pfankuch[5] heated barium benzoate with excess of barium thiocyanate and got benzonitrile but mixed with large quantities of other products. Barium acetate and barium thiocyanate gave similar results, the other products being in excess of the acetonitrile.

Kekulé[6] reviewed the work up to his time and speculated as to the mechanism of the reaction, but made no advance in its application.

G. Krüss[7] complained of the yield in Letts' process and improved the

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[1] *Ber.*, **5**, 669 (1872).

[2] *Ibid.*, **17**, 1766 (1884).

[3] *Am. Chem. J.*, **43**, 152 (1910).

[4] *Ber.*, **5**, 669 (1872).

[5] *J. prakt. Chem.*, [2] **6**, 97 (1873).

[6] *Ber.*, **6**, 111 (1873).

[7] *Ibid.*, **17**, 1766 (1884).

method by substituting lead thiocyanate for the potassium salt. Krüss gives the equation

$$2C_6H_5COOH + Pb(CNS)_2 = 2C_6H_5CN + PbS + H_2S + 2CO_2.$$

He reported a yield of 60 to 55 g. of benzonitrile from 100 g. of benzoic acid, or double what he was able to obtain by the method of Letts.

Reid[1] studied this reaction quantitatively and showed that it is not represented correctly by the equation given. He concluded that the nitrile is formed by interaction between the lead thiocyanate and the lead salt of the organic acid, this salt being formed by reaction between the free acid put in and a part of the lead thiocyanate. This led to a substitution of the previously prepared salt of the organic acid for the free acid, and to extended experiments with different salts, the conclusion being that the best yield is obtained when the zinc salt of the organic acid is used. Reid's method left little to be desired in the preparation of benzonitrile and other aromatic nitriles, both as to yield and convenience of work, but was not extended to aliphatic.

Materials.—*Lead thiocyanate* was prepared by precipitation from lead nitrate and ammonium thiocyanate. The precipitated salt was well washed with water, and twice with alcohol. The air-dried salt was further dried in an air-bath at 120°. The salt is pure white but turns somewhat yellow on long keeping. It blackens somewhat when dried in the air-bath.

Zinc thiocyanate was prepared by boiling ammonium thiocyanate with excess of zinc hydroxide till no more ammonia came off. The solution was filtered hot and evaporated to crystallization. The crystals were centrifuged. It is difficult to dry this salt as it fuses easily and begins to decompose at low temperatures. The salt is somewhat hygroscopic.

Cuprous thiocyanate was prepared by mixing copper sulfate and ammonium thiocyanate in the presence of sulfur dioxide. The gray salt was well washed with water and dried in an air-bath. It turns yellow.

Zinc acetate, calcium acetate, zinc butyrate, zinc propionate, and zinc isovalerate were prepared by boiling water solutions of the acids with excess of the carbonate of the metal. The solutions were filtered hot and evaporated to crystallization. The latter three salts were dried over sulfuric acid in a vacuum, the others were dried in an air-bath.

Zinc stearate, lead phenylacetate, zinc phenylacetate, lead cinnamate, zinc cinnamate, zinc hydrocinnamate, lead benzoate, and zinc terephthalate were prepared by double decomposition from the neutral ammonium or sodium salts of the acids and lead nitrate or zinc sulfate. All of these salts were dried in air-bath at 120°.

Potassium thiocyanate, lead acetate, copper acetate, barium acetate, basic

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[1] *Am. Chem. J.*, **43**, 162 (1910).

ferric acetate, stannous acetate, manganous acetate, nickel acetate, cobalt acetate, magnesium acetate, and strontium acetate were good commercial preparations.

Method of Work.—In each experiment the salts were thoroughly dried and powdered. The weighed amounts were thoroughly mixed before the heating was begun. As the heat is applied the mixtures melt and blacken and bubbles of gas and vapors come from the pasty mass. Usually the nitrile begins to drop from the retort neck in a very short time. The reaction proceeds regularly and spreads through the whole mass, which becomes more or less liquid throughout. At the end of the reaction, the nitrile ceases to come off and the residue sets to a hard mass of the sulfides of the metals.

Five methods of heating the mixtures were tried. In the tables the experiments are marked with the letters, *a*, *b*, *c*, *d*, and *e* to show in which of these ways the operation was carried out.

a. Heating in an iron retort under reduced pressure. The retort used was such as is sold for the distillation of mercury and was of 500 cc. capacity. The lid was luted on with a ring of asbestos paper wet with glycerine. Reduced pressure was maintained by a water pump. The heating was so regulated that the pressure was kept 50 to 100 mm.

b. Heating in the iron retort under atmospheric pressure. In this the same retort was used. In both cases the retort was heated by a ring burner which supplied the heat uniformly to the walls of the retort, additional heat being supplied by a Bunsen burner to complete the reaction. The distillates from the iron retort were somewhat more colored than those from glass, owing to small amounts of iron dissolved.

c. Heating in a glass retort. The retorts used were of 250 and 500 cc. capacity without tubulature. The heating was done by means of a Bunsen burner held in the hand, and the heat was applied at first one spot and then another on the side and finally at the bottom. The retort may be cleaned with nitric acid and used repeatedly. With the glass retort, the course of the reaction is readily followed and it is readily kept under control.

d. Heating in a horizontal glass tube. The tube used was of hard glass, 175 mm. long and 22 mm. in diameter, and closed at one end. The open end was closed by a cork through which a narrower tube passed to the condenser. The heating was done by a burner held in the hand. This was used for small scale experiments. It has the advantage that the nitrile does not condense and run back and does not remain so long in contact with the highly heated material.

e. Heating in a horizontal glass tube surrounded by a brass block. In this case the tube was of soft glass, 300 mm. long and 22 mm. in diameter, and closed at one end. The block was of cast brass and was 50 mm. square by 300 mm. long. A centrally located hole 25 mm. in diameter extended from one end to the other. The open end of the glass tube was closed by a cork carrying a smaller tube as in *d*. The end carrying the cork projected far enough out of the brass block to avoid burning the cork. The advantage in this method of heating is that the heat is applied regularly throughout the whole length of the tube and the intense local heating, caused by the direct application of the flame, is avoided. As all parts of the tube are above the boiling point of the nitrile, there is no condensation and running back of the nitrile. The brass block was heated by two Bunsen burners properly spaced.

In no case was much trouble experienced with foaming except with the mixture containing zinc thiocyanate. The last two methods gave much purer products, but the yields are much more uncertain, owing to the difficulty of working up the small amounts of the products. The losses of nitrile are proportionately greater than with the larger amounts. With these tubes only small amounts of materials can be used.

Working up Products.—The methods of separating the nitriles from the crude distillates were those commonly used in organic preparations.

The distillate containing acetonitrile or butyronitrile was diluted with half its volume of water, treated with solid potassium carbonate or ammonia gas to saturation, the upper layer separated and fractioned. In some cases, the total distillate containing acetonitrile was fractioned up to 85° and the distillate put through this treatment.

Propionitrile was separated by calcium chloride and the upper layer fractioned. Isobutyl cyanide was separated by fractionation.

In the cases of stearic, cinnamic, hydrocinnamic, and phenylacetic nitriles, the crude distillates were treated with a little water and a slight excess of ammonia and steam distilled. The nitrile was separated and the water layer extracted with ether. Stearic nitrile was also separated from the crude distillate by fractionation in a vacuum. It was never obtained pure.

The crude terephthalic nitrile was purified by sublimation. This gave beautiful short white needles melting at about 200°.

Results.—The results of the various experiments are brought together below in tables. Under "Ratio" is given the ratio of amount of the thiocyanate used to the calculated amount. Under "Prod." is given the weight of the crude product obtained by the distillation of the mixture of salts, and, in the next column, the weight of the nitrile isolated from such crude product. In the last column is given the yield in per cent. of the calculated.

Discussion of Results.

From Table I, in which are given experiments in which acetates of various metals were heated with lead thiocyanate, it appears that the acetates of the most of these metals give considerable yields of the nitrile. Nickel acetate gave little and magnesium acetate none that could be isolated. The distillates in Experiments 7 and 9 from mixtures containing magnesium and barium acetates had fearful, suffocating odors which may have been due to the presence of isocyanates. In an experiment, not included in the table, 75 g. of potassium thiocyanate were heated with 25 g. calcium acetate and only 1.2 g. of crude distillate was obtained. This had a similar bad odor.

TABLE I.

Acetates of Various Metals Heated with Lead Thiocyanate.

No.	Method.	Acetate.	Pb(CNS)$_2$.	Acetate.	Ratio.	Time.	Prod.	Nitrile.	Calc.	Yield.
1	*d*	Zn	4.0 g.	2.0 g.	1.14	30	4.0 g.	0.2 g.	0.9 g.	22%
2	*d*	Zn	11.0	5.0	1.25	75	1.4	0.56	2.2	25
3	*d*	Mn	20.0	9.0	1.20	90	3.0	3.0	4.3	70
4	*d*	Mn	10.0	4.2	1.28	45	1.1	0.5	2.0	25
5	*d*	Ni	10.0	5.0	1.37	45	1.5	0.1	2.3	4
6	*d*	Co	4.0	2.0	1.37	30	0.5	0.2	0.9	22
7	*d*	Mg	7.0	3.0	1.03	30	0.6	?	...	?
8	*d*	Sr	6.0	3.4	1.13	45	0.3	0.3	1.4	21
9	*d*	Ba	6.5	5.0	1.08	45	0.8	0.3	1.6	19
10	*c*	Cu	90	50	1.00	60	25	6.0	22.6	27
11	*c*	Pb	120	120	1.00	240	28	5.0	30.3	16
12	*c*	Pb	85	83	1.00	90	22	6.0	20.9	29
13	*c*	Pb	95	85	1.12	150	21	6.0	21.5	28

TABLE II.

Lead, Cuprous, and Zinc Thiocyanates with Zinc Acetate.

No.	Method.	Metal.	[1]M(CNS)$_2$.	Zn(AcO)$_2$.	Ratio.	Time	Prod.	Nitrile.	Calc.	Yield.
1	*d*	Pb	4.0 g.	2.0 g.	1.14	30	4.0 g.	0.2 g.	0.9 g.	22%
2	*d*	Pb	11.0	5.0	1.26	75	1.4	0.56	2.2	25
14	*d*	Cu	3.0	4.0	0.57	30	0.8	0.4	1.0	40
15	*e*	Zn	3.0	3.0	0.99	180	0.7	0.4	1.3	31

TABLE III.

Lead Thiocyanate and Zinc Acetate in Different Proportions and with Different Methods of Heating.

No.	Method.	Pb(CNS)$_2$.	Zn(AcO)$_2$.	Ratio.	Time.	Prod.	Nitrile.	Calc.	Yield.
16	*c*	90 g.	50 g.	1.03	210	23.0 g.	9.0 g.	22.4 g.	40%
17	*c*	72	20	2.05	120	11.0	4.0	8.9	45
18	*c*	115	60	1.09	195	28.0	15.5	26.8	57
19	*c*	50	25	1.13	150	7.0	1.4	11.2	12
20	spec.	18	10	1.02	180	3.0	1.0	4.5	22
1	*d*	4.0	2.0	1.14	30	4.0	0.2	0.9	22
2	*d*	11.0	5.0	1.26	75	1.4	0.56	2.2	25
21	*e*	6.0	3.0	1.13	60	1.5	0.8	1.3	61
22	*e*	6.0	3.0	1.13	60	1.2	0.3	1.3	24
23	*e*	6.0	3.0	1.13	180	0.6	0.3	1.3	24
24	*b*	40	20	1.13	180	7.4	4.1	8.9	46
25	*b*	100	50	1.13	420	19.8	11.3	22.4	50
26	*b*	140	70	1.13	420	26.5	17.8	31.3	57

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[1] M = Pb, Zn, or Cu'_2 as indicated in 3rd column.

TABLE IV.

Zinc Salts of Propionic, Butyric, Isovaleric, Stearic, Phenylacetic, Cinnamic, Hydrocinnamic, and Terephthalic Acids with Lead Thiocyanate.

No.	Meth.	Acid.	$Pb(CNS)_2$.	$Zn\bar{A}_2$.[2]	Ratio.	Time.	Prod.	Nitrile.	Calc.	Yield.
27	*e*	propionic	5.0 g.	3.0 g.	1.09	120	1.5 g.	1.1 g.	1.6 g.	71%
28	*c*	butyric	35.0	18.0	1.44	150	10.0	3.0	10.4	29
29	*e*	butyric	4.5	3.0	0.97	90	1.5	1.3	2.1	61
30	*b*	butyric	30.0	15.0	1.30	120	8.9	5.3	8.6	62
31	*e*	i.valeric	5.0	3.0	1.38	120	1.3	1.0	1.86	54
32	*e*	i.valeric	4.0	1.5	2.21	120	0.9	0.8	0.93	86
33	*a*	stearic	51	100	1.00	90	52	16	84	19
34	*a*	stearic	60	60	2.00	120	50	5	50	10
35	*c*	stearic	15	25	1.26	45	22	20	21	95?
36	*c*	phthalic	45	40	1.16	90	21	15	30	50
37	*a*	cinnamic	75	50	1.67	240	....	14	44	32
38	*a*	cinnamic	75	25	3.33	240	....	8	22	36
39	*c*	cinnamic	65	25	2.97	180	8	6	22	27
40	*c*	hydrocin.	35	35	1.12	90	21	18	25	72
41	*c*	hydrocin.	50	25	2.20	60	19	12	18	67
42	*d*	terephth.	5.0	3.0	1.18	30	1.0	1.0	1.7	59

TABLE V.

Lead Salts of Phenyl Acetic and Cinnamic Acid with Lead Thiocyanate.

No.	Method.	Acid.	$Pb(CNS)_2$	$Pb\bar{A}_2$.[1]	Ratio.	Time.	Prod.	Nitrile.	Calc.	Yield.
43	*a*	ph. ac.	35 g.	50 g.	1.03	120	15 g.	6.0 g.	24 g.	25%
44	*a*	cin.	100	75	2.04	150	....	8.0	37	21

In most of the first 9 experiments the amounts of materials used were small and the amounts of acetonitrile worked with were quite small. On this account the losses in handling the nitrile were proportionately great and the results given, representing the amounts isolated, are probably much too low. It appears from these experiments that manganese and zinc acetates are the most suitable for the preparation of the nitrile. The manganese acetate gave a particularly high yield and a clean pure product, but as zinc salts are so much more readily obtained than those of manganese, the zinc salts are to be preferred for practical work.

Experiments 10, 11, 12, and 13 with copper and lead acetates, in glass retorts using larger amounts of materials, are to be compared with Experiments 15, 17, and 18 of Table III in which zinc acetate was used under the same conditions. It thus appears that zinc acetate gives nearly twice the yield that lead acetate does. The stability, fusibility, and mutual solubilities of the fused salts are probably the determining factors in the matter of the yields from various mixtures.

From the results in Table II, it appears that thiocyanates of other heavy metals can be used. In Experiment 14 an excellent yield was obtained from cuprous thiocyanate. In this case the yield is calculated from the thiocyanate present instead of from the acetate as in all the

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[1] Ā stands for one equivalent of the acid indicated by abbreviation in 3rd column.

other experiments. The results obtained with zinc thiocyanate suggest that it might be substituted for the corresponding lead salt to advantage, but its physical properties make against its use. Lead thiocyanate, being insoluble in water, is readily obtained by precipitation, and is easily dehydrated. Zinc thiocyanate is very soluble in water and hence inconvenient to prepare and is difficult to dehydrate. For these reasons the lead salt is better for practical work.

From the results given in Table III, it appears that much better results are obtained by methods *c* and *b* in which larger quantities of materials are used in glass or iron retorts. Contrasting Experiment 16 with Experiment 17 in which double the calculated amount of the lead sulfocyanate was used, it appears that little or nothing is gained by the use of this large excess.

From the experiments in Table IV, it appears that the yields are better with the higher molecular weight acids than with acetic, isovaleric giving 86% of the calculated amount of nitrile. This may be only apparent, since the higher nitriles, on account of their being less volatile and less soluble in water, are much easier to isolate than is acetonitrile. The results with stearic acid are not regarded as reliable as no good method is available for the isolation of this nitrile.

Comparing Experiments 37 to 39 with 40 and 41, we see the effect of the ethylene group in cinnamic acid. A much larger yield of hydrocinnamic nitrile is obtained than of the cinnamic. The use of diminished pressure during the distillation in Experiments 37 and 38 did not materially increase the yield. The high yield of hydrocinnamic nitrile, when the mixture of salts is heated in a plain glass retort, is surprising. This shows that the method is available for the preparation of nitriles of high molecular weight, provided there are no interfering groups in the molecule.

In this work, the mixed aromatic-aliphatic acids in which the carboxyl group is not in the ring are considered as aliphatic.

Experiment 42, with terephthalic acid, an aromatic acid, does not properly belong to this study, but was tried to test the applicability of the method for di-nitriles.

The experiments in Table V, with lead salts, are to be compared with those with the corresponding zinc salts in Table IV. The comparison is to the advantage of the zinc salts as it was with the acetates in Table I.

According to Liebig and Rammelsburg[1] and also Voelckel,[2] thiocyanic acid decomposes when heated, in presence of water, into carbon dioxide, carbon disulfide, and ammonia.

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[1] *Pogg. Ann.*, **56**, 94 (1842).

[2] *Ibid.*, **58**, 135 (1843); *Ann.*, **43**, 74 (1842).

$$2HCNS + 2H_2O \longrightarrow CO_2 + CS_2 + 2NH_3$$
$$HCNS + 2H_2O \longrightarrow CO_2 + H_2S + NH_3.$$

It was thought that possibly some of these decomposition products might act on the lead salt of an acid to give the nitrile. Accordingly an experiment was performed to determine the effect of the decomposition products of thiocyanic acid on the lead salt of benzoic acid. Dry ammonia was passed through carbon disulfide which was sufficiently warmed to give it the proper vapor tension. The mixture of the vapors of ammonia and carbon disulfide was passed over lead benzoate (39 g.), which was heated in an oil bath to a temperature of 220°. *Results:* a mixture of benzoic acid and benzonitrile condensed on the cooler part of the lead benzoate flask and also in the condenser. A few drops of a pale yellow liquid passed through the condenser. This had an odor of carbon disulfide. All the lead benzoate was converted into a black residue of lead sulfide, with black mirror of same around the upper part of the flask. The amount of benzonitrile formed was insignificant. This shows that ready formed CS_2 and NH_3 do not produce the same results as the lead thiocyanate.

In another experiment, a mixture of ammonia and carbon dioxide was passed over a mixture of 35 g. of lead benzoate and 5 g. of sulfur, heated in an oil bath to a temperature of 240°. *Results:* Solid ammonium carbonate was deposited on the walls of the lead benzoate flask and in the condenser and also in the receiver. Sulfur sublimed and deposited on the upper part of the flask. The odor of benzonitrile was apparent but the amount formed was insignificant.

In Experiment 20, to determine whether the nitrile is decomposed by side reactions, etc., into the free acid, the mixture of zinc acetate and lead thiocyanate was heated in an oil bath with reflux condenser. The blackening began between 150 and 170° and the reaction began at about 250°. The mixture was kept at this temperature for a considerable time and then the bath was removed and the heating completed with a luminous flame. The nitrile was finally distilled off. The yield was less than usual, showing that prolonged contact of the nitrile with the heated mass lowers the yield.

Stannous and basic ferric acetates were heated with lead thiocyanate but the mixtures did not fuse and gave no nitrile. In the case of the ferric salt, a white solid was deposited in the condenser. This proved to be ammonium carbonate.

In several experiments, the issuing gases were measured and examined. No hydrogen sulfide was found. A small amount of carbon monoxide was found. The amount of carbon dioxide corresponded closely to that calculated from the reaction given below.

Conclusions.

1. Aliphatic nitriles, as well as aromatic, are readily prepared, with good yields, by distilling mixtures of well dried heavy metal salts of the acids with slight excess of lead, or other thiocyanate.

2. All things considered, the best mixture is the *zinc* salt of the organic acid with *lead* thiocyanate.

3. The reaction takes place, in the main, according to

$$(RCOO)_2Zn + Pb(CNS)_2 \longrightarrow 2RCN + PbS + ZnS + 2CO_2.$$

4. Excess of the thiocyanate and use of vacuum do not materially increase the yields.

5. *Preparation of Acetonitrile.*—A mixture of one part well dried zinc acetate and two parts, by weight, of lead thiocyanate is heated in a plain glass retort till no more distillate comes over. The crude distillate is mixed with half its volume of water, saturated with solid potassium carbonate or ammonia gas and the nitrile separated and fractioned.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF JOHNS HOPKINS UNIVERSITY.]

STUDIES IN THE PREPARATION OF NITRILES. III. THE CATALYTIC PREPARATION OF NITRILES.

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Introduction.

Numerous experiments have recently been described, in which substances have been made to react, with elimination of water, by passing them, in vapor form, over certain metallic oxides, notably alumina and thoria. Thus Senderens[1] prepared ethers by passing vapors of the alcohols over alumina at 240–260°. Sabatier and Mailhe[2] found that alcohols yield ethylene hydrocarbons and water with thoria and alumina at 300–350°, and that various phenols[3] when mixed with methyl alcohol give the methyl ethers of the phenols with thoria at 390–420°, or the diphenyl ethers[4] when the alcohol is left out. The same authors[5] found that, when a mixture of the vapors of an acid and an alcohol is passed over titania or thoria at 280°, esterification takes place with great rapidity, the limit of esterification being reached in minutes instead of the hours required at 154° or 200°, without catalyst.

Since the formation of a nitrile from the acid and ammonia

$$CH_3COOH + NH_3 \longrightarrow CH_3CN + 2H_2O$$

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[1] *Compt. rend.*, **148**, 227–8 (1909).

[2] *Ibid.*, **150**, 823–6 (1910).

[3] *Ibid.*, **151**, 359–62 (1910).

[4] *Ibid.*, **151**, 492–4 (1910).

[5] *Ibid.*, **152**, 494–497, 1044–47 (1911); *Chem. Ztg.*, **35**, 193 (1911).