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.

Baltimore, Md.

[Contribution from the Chemical Laboratory of Johns Hopkins University.]

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

By G. D. Van Epps and E. Emmet Reid.

Received August 2, 1916.

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).

may be regarded as a dehydration reaction, it was thought that it might take place under similar circumstances. The experiments have justified this supposition, since it has been found that excellent yields of acetonitrile may be obtained directly from acetic acid and ammonia, by passing their vapors over alumina or thoria at 500°.

The study of this reaction may throw some light on the mechanism of the other reactions since, in this case, we are well acquainted with ammonium acetate which may be formed as an intermediate product in the reaction.

Acetic acid has been the only acid studied, but it is probable that other acids will yield nitriles under similar circumstances.

As usually made, from acetamide and phosphorus pentoxide, both of which are rather expensive, acetonitrile is an expensive substance and one difficult to prepare in large quantities. By the present method in which it is made in a direct continuous process from acetic acid, and ammonia, both cheap materials, it becomes one of the most accessible compounds.

Experimental.

Materials.—A high grade glacial acetic acid containing very near 100% acid was used. Weighed amounts of this were diluted with weighed amounts of water for the acids of 95%, 90%, etc., strength. The other chemicals used were good commercial products. The ammonia was drawn directly from a cylinder of the liquefied gas.

The Catalyst.—Pumice stone, broken to pieces 3 to 5 mm. in diameter, was soaked in a concentrated solution of aluminium sulfate, treated with ammonium hydroxide, and well washed. The pumice stone with the adhering aluminium hydroxide was at first dried in an air bath, but later was dried in the copper tube in a current of ammonia.

For the thoria catalyst, the pumice stone was wet with a concentrated solution of thorium nitrate and heated to about 500° in a current of ammonia.

Apparatus.—The catalyst was placed in a very thick walled copper tube 762 mm. long and 32 mm. bore, heated by long burners. This will be more fully described elsewhere. The acid was run in through a brass tube containing a trap to prevent the exit of vapors. This ended about 80 mm. inside the copper tube so that the acid was vaporized on entering. Around this tube was a larger but shorter tube, through which the ammonia was introduced. Thus the acid vapor was introduced directly into an atmosphere of ammonia at the reaction temperature.

The exit end of the copper tube was connected through a Liebig condenser with a receiver from which a tube led to a flask of dilute sulfuric acid to absorb any excess of ammonia gas.

The temperature of the copper tube was measured by an arrangement by which the expansion of the tube itself was made to move a hand on a dial.

Procedure.—The acid or other liquid was dropped into the funnel of the trap tube from a small dropping funnel at a rate of one drop per second. The ammonia was passed in at such a rate that white vapors filled one-half the condenser tube. This shows presence of sufficient excess of ammonia.

Usually the product in the receiver forms two layers, the upper one being nearly pure nitrile, and the lower containing some nitrile and much ammonium acetate. Acetonitrile is salted out of water by ammonium acetate. On completion of each experiment, the upper layer of nitrile was separated and distilled up to 85°. The lower layer was fractionated up to 90°, the fraction being redistilled up to 82–84°. The total nitrile obtained is the sum of these two portions. In cases where no layer was observed the whole product was fractionated up to 90°, the lower fraction being redistilled up to 85°.

Results.—The first experiment with alumina at above 500° showed the production of nitrile. Then a large number of experiments were made in order to find the best conditions as to catalyst, temperature, relative amounts of ammonia, etc. The results of these are given below in tabular form.

It was thought possible that ethyl acetate might react with ammonia

$$CH_3COOC_2H_5 + NH_3 \longrightarrow CH_3CN + HOC_2H_5 + HOH$$

and accordingly this was tried with alumina at 510°, but no nitrile was obtained. It is known that acetone passed over pumice at 500° gives ketene[1] which might possibly react with ammonia to form the nitrile.

$$CH_3COCH_3 \longrightarrow CH_2 : CO + CH_4.$$

$$CH_2 : CO + NH_3 \longrightarrow CH_3CN + H_2O.$$

Accordingly, acetone vapor and ammonia were tried at 500° with alumina, but no nitrile was obtained.

It was thought that acetic anhydride might give better yields with ammonia than acetic acid, since less water would have to be split off. Accordingly, two experiments were tried, using the anhydride at 500–530° and at 520–560°. These gave 31.3 and 24.4% of the calculated amount of nitrile. As these were lower yields than were usually obtained with the 100% acid the use of the anhydride appears to be of no advantage and no further experiments were tried with it. The anhydride would, doubtless, have given better yields with the better catalyst that was used in later work with acetic acid.

In order to ascertain whether a catalyst is required, two experiments were tried in which acetic acid and ammonia were passed through the

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[1] Schmidlin and Bergman, *Ber.*, 43, 2821 (1910).

hot tube filled with broken pumice stone at 400° and at 500° but no nitrile could be isolated in either case. The product seemed to be mainly acetamide.

The next experiments were to determine the relative activity of the two catalysts, alumina and thoria at various temperatures with 100% acetic acid. The four experiments with alumina were run with same catalyst without removing it from the copper tube and the four with thoria likewise. The results are given in Table I and graphically in Fig. 1.

TABLE I.

			With thoria.		With alumina.	
Temp.	Acid used.	Time in minutes.	Grams.	Per cent.	Grams.	Per cent.
305°	20.0 g.	..	None	....	....	....
300°	107.5	80	....	....	6.0	8.2
405°	57.9	65	3.5	8.8	....	....
400°	118.0	65	....	....	15.0	18.6
500°	66.0	75	15.4	34.1	....	....
500°	89.0	60	....	....	21.5	35.3
550°	83.5	85	10.5	18.4	....	....
575°	120.0	55	....	....	21.8	26.6

For the lower temperatures the alumina gives decidedly better results. About 500° appears to be the best temperature with both catalysts. The results are plotted in curves with the percentage yield against temperature. Too much reliance must not be put in these figures, since the results given below show that there is great variation in the yields without apparent cause, and that different preparations of the same catalyst give widely different results. As the alumina appears to be slightly more effective than the expensive thoria, the alumina catalyst was used exclusively in the remainder of the work. In the experiments at 300° and 400° with both catalysts, acetamide seemed to be present in the product, but it was not positively identified.

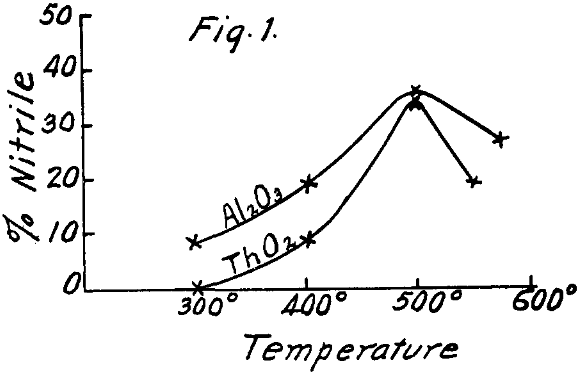
Fig. 1.

The remaining experiments are all given in Table II, the two main variables being percentage of acetic acid and the preparation of the catalyst. Experiments were run with differing concentrations of the acid with one lot of catalyst, and then the copper tube would be cleaned out and another lot of catalyst put in and more experiments run. A blank space across the table indicates this change to a new lot of catalyst, the double space at Expt. 39 indicates change in method of preparation of catalyst. The temperature was near 500° in all. The experiments are numbered in the order in which they were run.

The catalyst becomes covered with a black deposit and loses its activity. The method of estimating the nitrile gives, only approximate results. It represents not the amount formed, but the amount that may be isolated according to methods in use in ordinary organic preparations. The accuracy of the work naturally increases toward the end.

TABLE II.

No. of experiment.	Strength of acid.	Temperature. Start. End.	Time in minutes.	Acetonitrile.				Yield in per cent.
				Upper layer.	Lower layer.	Total.	Calculated.	
1	100%	500–500°	135	....	...	14.8	41.0	36.1
2	100%	520–550°	99	10.7	2.2	12.9	41.0	31.5
3	100%	510–505°	63	16.6	4.3	20.9	41.0	50.2
4	100%	500–500°	42	....	...	18.4	41.0	43.9
5	100%	510–505°	13	....	...	10.1	41.0	24.7
6	90%	505–505°	60	16.9	8.8	25.7	36.9	69.6
7	80%	500–510°	30	11.4	3.9	15.3	32.8	46.6
8	95%	500–505°	45	18.9	3.2	22.1	38.9	56.8
9	95%	500–500°	35	19.7	1.6	21.3	38.9	54.7
10	95%	500–500°	45	22.1	0.9	23.0	38.9	59.1
11	90%	500–520°	35	9.6	3.4	13.0	36.9	35.2
12	90%	505–505°	60	15.6	2.5	18.1	36.9	49.0
13	90%	510–510°	55	12.2	3.1	15.3	36.9	41.4
14	90%	500–505°	35	9.8	2.9	12.7	36.9	34.4
15	90%	510–505°	45	12.0	2.7	14.7	36.9	39.8
16	85%	500–500°	50	9.3	4.3	13.6	34.9	38.9
17	85%	525–510°	45	11.0	4.2	15.2	34.9	43.5
18	85%	505–525°	40	12.4	3.1	15.5	34.9	44.4
19	85%	505–510°	50	15.3	2.5	17.8	34.9	51.0
20	85%	510–510°	40	12.2	3.5	15.7	34.9	44.9
21	80%	500–510°	40	13.4	2.8	16.2	32.8	49.3
22	80%	505–510°	40	13.4	3.4	16.8	32.8	51.2
23	80%	515–510°	45	13.9	1.6	15.5	32.8	47.2
24	75%	510–520°	45	13.2	4.1	17.3	30.8	56.2
25	75%	500–525°	55	9.1	8.2	17.3	30.8	56.2
26	75%	505–520°	65	10.5	6.6	17.1	30.8	55.5
27	70%	500–500°	55	8.0	4.2	12.2	28.7	42.5
28	70%	500–500°	60	4.3	7.7	12.0	28.7	41.8
29	70%	500–500°	50	7.2	5.8	13.0	28.7	45.2
30	95%	500–525°	55	13.0	3.6	16.6	38.9	42.6
31	95%	510–520°	55	18.8	3.7	22.5	38.9	57.7
32	90%	520–525°	65	19.9	5.3	25.2	36.9	68.3
33	90%	500–525°	65	13.8	8.5	22.3	36.9	60.4
34	85%	510–520°	60	10.5	8.5	19.0	34.9	54.4
35	80%	500–525°	65	....	...	16.4	32.8	50.0

TABLE II—(*Continued*).

No. of experiment.	Strength of acid.	Temperature.	Time in minutes.	Acetonitrile.				Yield in per cent.
		Start. End.		Upper layer.	Lower layer.	Total.	Calculated.	
36	85%	500–525°	55	10.8	6.6	17.4	34.9	49.8
37	85%	500–520°	70	7.5	10.3	17.8	34.9	51.0
38	75%	500–520°	50	6.6	6.6	13.2	30.8	42.8
39	75%	510–540°	60	....	...	13.8	30.8	44.8
40	75%	520–535°	50	14.9	7.0	21.9	30.8	71.1
41	75%	525–530°	55	13.6	6.9	20.5	30.8	66.5
42	95%	510–525°	65	22.0	6.8	28.8	38.9	74.0
43	95%	505–520°	55	23.9	3.3	27.2	38.9	70.0
44	90%	500–515°	50	16.6	5.6	22.2	36.9	60.1
45	90%	500–515°	60	18.8	4.0	22.8	36.9	61.7
46	85%	515–525°	80	16.1	5.4	21.5	34.9	61.6
47	85%	505–520°	55	16.9	2.0	18.9	34.9	54.1
48	75%	510–530°	60	11.1	5.6	16.7	30.8	54.2
49	100%	510–530°	50	19.9	2.9	22.8	41.0	55.6
50	100%	505–530°	55	25.9	8.8	34.7	41.0	84.6
51	100%	505–530°	75	31.7	3.5	35.2	41.0	85.8
52	95%	510–520°	55	17.9	3.9	21.8	38.9	56.0
53	95%	520–520°	55	25.3	2.4	27.7	38.9	71.2
54	90%	510–520°	60	20.5	3.7	24.2	36.9	65.5
55	90%	510–520°	50	16.3	2.0	18.3	36.9	49.5
56	85%	520–520°	60	16.1	4.5	20.6	34.9	59.0
57	85%	505–520°	55	10.6	4.8	15.4	34.9	41.7

Discussion of Results.

In Expt. 3 a small excess of ammonia was used and in Expt. 4 a much more rapid current of ammonia. The smaller amount gave 50.2% against 43.9% for the larger. This seems strange, at first sight, but the rapid current of ammonia hurries the acid vapor through the hot tube and does not give it time to react. In Expt. 5 the flow of the acid was four times as rapid as in Expt. 3 and only about half as large a yield of nitrile was obtained, but twice as much nitrile per minute was formed.

A calculation as to the rapidity of the reaction is of interest. Since 60 g. of acetic acid is 1 mol its vapor should occupy at 500°, $\frac{22.4 \times 773}{273} =$ 63 l. = 63,000 cm. As the bore of the tube is 32 mm., its area is 8.0 sq. cm. Dividing 63,000 by 8, we have 7,875 as length of a tube of this size required to contain the acetic acid vapor. In Expt. 50, this amount of acid vapor passed through the tube in 55 minutes, from which the linear velocity of the vapor must be $7875 \div 55 = 143$ cm. per minute. As the length of the tube is 76.2 cm. the vapor must pass through the tube in one-half minute. This calculation has been made assuming that there is nothing in the tube but acetic acid vapor, while in the actual experiment there was more than an equal volume of ammonia. This more than doubles the linear velocity and reduces the time that any one portion of the vapor is in the tube to one-fourth of a minute or less. Hence, a mixture of acetic acid vapor and ammonia, at 500°, in contact with alumina is 85% transformed to nitrile in less than 15 seconds. If this is the average velocity for the whole mass of vapor, the velocity of the reaction in the layers of the vapor in actual contact with the alumina must be enormous.

It appears from many experiments that the addition of moderate amounts of water to the acetic acid does not prevent the formation of the nitrile. In fact, in the earlier part of the work, it seemed that the yields were increased by the addition of water, but the layer and more reliable experiments show a diminution of yield with increase of water present. Since water has a much smaller molecular weight than acetic acid, the molecular percentage of water in the mixture is much larger. The effect of the water is seen from Table III in which some of the experiments from Table II are presented in a different way. In the last column the yields obtained, with the diluted acids, are calculated as per cents. of the yield from 100% acetic acid.

TABLE III.

Showing Effect of Water on Yield.

Experiment.	Per cent. acid.	Actual yield.	Mol. % of acid.	Yield ÷ 85.
50	100	84.6	100	100%
51	100	85.8	100	100%
53	95	71.2	85	83%
54	90	65.5	73	77%
56	85	59.0	63	70%

The results are as we should expect from the mass law, since the rate of formation of nitrile appears to be roughly proportioned to the concentration of the acid in every case. The water found in the reaction diminishes the effect of the water initially present so that it is not surprising that the weaker acids give better yields than would be expected from the initial composition of the mixture. Good yields, 42 to 45%, were obtained with even 70% acetic acid. The average of 8 experiments with 75% acid is 56% of nitrile, which is better than any results obtained with 80% acid. It is not safe to draw too definite conclusions, as there is a large variation in the results. This variation comes partly from errors in the method of estimation of the nitrile, but mostly from slight changes of conditions in the various experiments, conditions that it is very difficult to control.

Inspection of consecutive experiments shows that the activity of the catalyst gradually diminishes with use and a jump in the yield is noticed on the introduction of a new lot of catalyst.

In one experiment, not included in the table, ammonium acetate dissolved in an equal weight of acetic acid was used instead of the acid.

Only a little nitrile was obtained. In Expt. 2 the lower layer of the distillate was passed through the apparatus again, but only a small additional amount of nitrile was produced.

It appears from Table II that most of the nitrile is found in the upper layer and, when 100% acid is used, a good yield of the nitrile is obtained even when the lower layer is discarded. As we would expect, in the experiments with weaker acid, particularly the 70% acid, a larger amount, in some cases, half or more of the nitrile, is found in the lower layer.

It is intended to continue this work, particularly with the study of the formation of other nitriles.

Summary.

1. It is found that acetic acid vapor, mixed with a moderate excess of ammonia and passed over alumina or thoria at 500°, gives a large yield, up to 85%, of acetonitrile.

2. This reaction does not take place in case the catalyst is omitted.

3. The yield depends on the activity of the catalyst and may vary greatly for what appear to be trifling differences in the method of preparation of the catalyst.

4. So far as the present work goes, alumina appears to be the best catalyst and about 500° the best working temperature.

5. This method of preparation of acetonitrile is a continuous process requiring very little attention, and is adapted to use for the preparation of large quantities.

BALTIMORE, MD.

[CONTRIBUTIONS FROM THE SHEFFIELD CHEMICAL LABORATORY OF YALE UNIVERSITY.]

RESEARCHES ON AMINES. V. THE STRUCTURE OF VITIATINE. SYNTHESIS OF METHYLETHYLENEDIAMINE.[1]

BY TREAT B. JOHNSON AND GEORGE C. BAILEY.

Received July 26, 1916.

The only compound conforming in constitution to the expression $C_5H_{14}N_6$, that is recorded in Richter's Lexikon der Kohlenstoffverbindungen is the base *Vitiatine* whose structure has never been established. This interesting substance was isolated by Kutscher[2] from beef extract by precipitation in the form of its gold salt, which gave analytical values agreeing with that calculated for $C_5H_{14}N_6.2HCl.2AuCl_3$. Later, during a careful investigation of the nature of the toxic bases in urine, Kutscher[3] identified the same amine and ascribed its origin, in this case to the metab-

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[1] This paper was constructed from a Dissertation presented by Mr. George Corbin Bailey to the Faculty of the Graduate School of Yale University, 1916, in candidacy for the Degree of Doctor of Philosophy.

[2] *Zentr. Physiol.*, 21, 33 (1907).

[3] *Z. physiol. Chem.*, 51, 457 (1907).