[Contribution from the Laboratory for Organic Chemistry of the Technical High School, Delft, Holland]

The Influence of the Degree of Acidity upon the Velocity of the Diazotization Reaction[1]

By H. A. J. Schoutissen

It appears from the results obtained by studying the velocity of the diazotization reaction[2] that the following arguments hold good. (1) The diazotization reaction is a bimolecular one. (2) When a group has been introduced into aniline, it will especially influence the diazotization velocity if it is situated in the ortho position; in the para derivative the influence is less strong, in the meta derivative it is commonly feeble, except when the very strongly negative nitro group is present. (3) The velocity of diazotization increases with the "negativeness" of the substituent.

Now it was of interest to ascertain whether the velocity of diazotization is dependent on the basicity of the amine as well. Herein the consideration is included that up to now the possibility is not excluded that the reaction takes place between the free amine and nitrous acid, as opposed to the second possibility that the reaction proceeds between the *salt of the amine* and nitrous acid, in other words *whether the tervalent or the pentavalent nitrogen condition is required.* According to the first supposition the reaction will proceed with the greatest velocity for the weakest bases, as their salts are hydrolyzed to a very large extent. In this case one could interpret the results of the first investigation[2] by arguing that the increased velocity of diazotization of the negatively substituted amines together with the order of succession, meta, para, ortho, is parallel to the amount of free amine by hydrolysis. Therefore it is of great importance to prove whether the reaction proceeds according to the first or after the second equation

$$C_6H_5NH_2 + HNO_2 \longrightarrow C_6H_5N_2OH + H_2O \quad (I)$$
$$C_6H_5NH_3Cl + HNO_2 \longrightarrow C_6H_5N_2Cl + 2H_2O \quad (II)$$

A decision can be arrived at by tracing the velocity of the diazotization reaction of amines with the addition of a surplus of mineral acid.

***Case I. The Diazotization Proceeds between* Free Amine and Free Nitrous Acid.**—Amount of free amine α, initial concentration of amine (amine salt and amine) and nitrous acid $= a$. Quantity transformed after t min. $= x$. Now the velocity of diazotization is given by

$$dx/dt = \alpha(a - x)K_1 \quad (I)$$

The concentration of the free acid is fixed by: (a) the quantity used of hydrochloric acid, b; (b) less the hydrochloric acid, necessary to liberate the nitrous acid, a; (c) less the quantity of hydrochloric acid x, which is fixed during the diazotization

$$C_6H_5NH_2 + HNO_2 \longrightarrow C_6H_5N_2OH + H_2O$$
$$C_6H_5N_2OH + HCl \longrightarrow C_6H_5N_2Cl + H_2O$$

(d) less the quantity of hydrochloric acid fixed as hydrochloric acid salt of the amine, $a - \alpha - x$. The concentration of free acid is therefore $b - a - x - a + x + \alpha$.

$$K_2 = \frac{C_{\text{free amine}} \times C_{\text{free acid}}}{C_{\text{amine salt}} \times C_{\text{water}}}$$
$$K_3 = \frac{\alpha(b - 2a + \alpha)}{a - \alpha - x}$$

If we consider the cases in which $b > 3a$, α apart from the initial and final phases of the reaction (*e. g.*, for aniline, *o*-, *p*-, *m*-toluidine) is only small with respect to $(b - 2a)$ and $(a - x)$, can be neglected as far as concerns these magnitudes. The equation now changes into

$$K_3 = \frac{\alpha(b - 2a)}{a - x}$$

or

$$\alpha = \frac{K_3(a - x)}{b - 2a}$$

Substituting this expression of α in equation (I), we obtain

$$\frac{dx}{dt} = \frac{K_3(a - x)^2K_1}{b - 2a} = \frac{K_4(a - x)^2}{b - 2a}$$

from which it appears that the velocity of the bimolecular reaction is inversely proportional to the excess of hydrochloric acid $(b - 2a)$.

Case II. The Diazotization Proceeds between the Amino Salt and Free Nitrous Acid.—Suppose now the concentration of free amine $= \gamma$, the initial concentrations of amine + amine salt and nitrous acid $= a$, the inverted quantities after t minutes $= x$. Now we find for the velocity of diazotization

$$\frac{dx}{dt} = K_1(a - x)\,(a - x - \gamma) \quad (I)$$
$$K = \frac{C_{\text{amine}} \times C_{\text{free acid}}}{C_{\text{amine salt}} \times C_{\text{water}}} \quad (II)$$

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[1] Original manuscript received January 26, 1935.

[2] Böeseken, Brandsma and Schoutissen, *Verhandel. Akad. Wetenschappen Amsterdam*, **28**, 936 (1920); Schoutissen, These, Delft, "Studies in de diazochemie," 1926, p. 13, etc.

The amount of free base in this case is γ, the concentration of amine salt $= a - \gamma - x$. The concentration of the free acid $= b - a + \gamma + x - a - x$. The concentration of water during the reaction is constant. By substituting equation (II) changes into

$$K_2 = \frac{\gamma(b - 2a + \gamma)}{a - \gamma - x}$$

If $b > 3a$ we may, apart from the final phases of the reaction, neglect γ as regards $(b - 2a)$ and $(a - x)$ for the amines with a small constant of hydrolysis

$$K_2 = \frac{\gamma(b - 2a)}{a - x}$$

Substituting γ from this expression in (I) we obtain

$$\frac{\mathrm{d}x}{\mathrm{d}t} = K_1(a - x)\left\{a - x - \frac{K_2(a - x)}{(b - 2a)}\right\}$$

$$\frac{\mathrm{d}x}{\mathrm{d}t} = K_1(a - x)^2\left(\frac{b - 2a - K_2}{b - 2a}\right)$$

After integration we find

$$K_1\left(\frac{b - 2a - K_2}{b - 2a}\right) t = \frac{x}{a(a - x)}$$

Comparing the times in which one-half of the original quantity of free nitrous acid is inverted for

$$b = 3a;\ b = 4a;\ b = 6a;\ \text{and } b = 8a$$

we find ($x = {}^1/_2\, a$)

$$t_{1/2} = \frac{b - 2a}{K_1(b - 2a - K_2)a}$$

The relation between the $t_{1/2}$ for $b = 3a$, $4a$, $6a$ and $8a$ is therefore

$$\frac{1}{K_1(a - K_2)} : \frac{2}{K_1(2a - K_2)} : \frac{4}{K_1(4a - K_2)} : \frac{6}{K_1(6a - K_2)}$$

or, on the assumption that K_1 does not change by the excess of hydrochloric acid (catalysis)

$$\frac{1}{a - K_2} : \frac{2}{2a - K_2} : \frac{4}{4a - K_2} : \frac{6}{6a - K_2}$$

in which K_2 is the constant of hydrolysis of the amine. We see therefore that the reaction proceeds with a greater velocity as the excess of hydrochloric acid is greater. It also appears that the influence of the excess of hydrochloric acid will assert itself the longer in proportion to the decreasing basicity of the amine. The differences in velocity of the reaction of diazotization between the ortho, para and meta derivatives will therefore be still more accentuated than appeared from the previous investigation.[2] In the case now mentioned we have up to now neglected γ in the expression of K_2 as regards $(b - 2a)$ and $(a - x)$. For $b = 2a$, however, and also for the amines with great constant of hydrolysis this simplification is not permitted. In this case γ must be substituted in equation (I) by

$$\gamma = \frac{2a - b - K_2}{2} + \sqrt{\frac{(2a - b - K_2)^2}{4} + aK_2 - xK_2}$$

Integration of this term gives a complicated relation between the constant of velocity and x, which is of no importance to the present case.

We see, consequently, that the influence of the addition of hydrochloric acid can be studied in the simplest way in the case of $b > 3a$. If hydrochloric acid in surplus in itself exercises no specific influence as to the velocity of the reaction of diazotization (in case of the alteration of the medium, catalysis, etc.), it may be expected that "case II" accords with the mathematical figures. In the opposite case it may be attributed to the presence of the factors mentioned above. It appears that in the case $b < 3a$ a decision is possible whether the reaction proceeds according to case I or II; the experiments with $b < a$ give a more evidential proof as to the kind of reaction than is to be expected if $b > 3a$, whereas especially the mean concentrations of hydrochloric acid influence the velocity of the reaction to a high degree.

It has appeared from the experiments, as is shown by the figures and tables, that the velocity of the reaction of diazotization is *not inversely* proportional to the excess of hydrochloric acid $(b - 2a)$. By adding more hydrochloric acid the velocity increases for all the amines which were investigated. Therefore, it is evident that the reaction does *not* proceed between free amine and nitrous acid. It must be concluded from the figures obtained by matching the reaction in the presence of small concentrations of hydrochloric acid that the reaction proceeds between amine salt (*pentavalent nitrogen*) and nitrous acid, as the reaction is accelerated by the addition of a surplus of hydrochloric acid. This is in accordance with the results of previous investigators.[3] However, it appears from the figures mentioned below that the extra addition of hydrochloric acid exceeds to a high degree the factor of affinity of the corresponding amines. This is evident from the formulas given above and the figures of the tables.

Therefore, there must be another factor which is responsible for the acceleration of the reaction of diazotization; experiments in this direction are continued.

[3] Hantzsch and Schumann, *Ber.*, **32**, 1691 (1899); Schumann, *ibid.*, **33**, 527 (1900); Tassilly, *Bull. soc. chim.*, **27**, 19 (1920).

Experimental Part

Before beginning the study of the diazotization reaction in the presence of small quantities of hydrochloric acid, an amine had to be found, which under the circumstances, mentioned above, does not give any trouble caused by the formation of diazoamino compounds.

Now the diazotization of *p*-toluidine with the addition of 1 equivalent of hydrochloric acid (which is necessary for the liberation of nitrous acid) does not give any separation of a colored by-product after six hours, the reaction mixture remains colorless at 0°; after many hours a red-violet coloration appears. Other amines behave in a different way. In the same circumstances *o*-chloroaniline gives an opaque solution after twenty minutes; after forty minutes (at 0°) a yellow precipitate has been observed. This also appears with two equivalents of hydrochloric acid and in the case of three equivalents of hydrochloric acid the diazotization is not disturbed. For *m*- and *p*-chloroaniline the limit is about 2 equiv. For α-naphthylamine the reaction mixture becomes colored even with the addition of 5 equiv. of hydrochloric acid.

We operated as follows: 5 cc. of 0.2 *N* hydrochloric acid is added to 50 cc. of a solution of *p*-toluidine 0.02 *N* and this mixture is diluted to 100 cc. This solution containing 0.001 mole of amine and hydrochloric acid is cooled with ice to 0°. The second solution contains in 400 cc., 0.001 mole of sodium nitrite, titrated with potassium permanganate. When both the solutions have been cooled to 0° they are mixed with vigorous stirring and the stop-watch is started. After various times 5 cc. of the reaction mixture is taken by a pipet (cooled in a tube to 0°) and coupled at 0° with 5 cc. of a solution of Schäffer salt.

CONSTANTS OF VELOCITY OF THE DIAZOTIZATION REACTION OF SOME AMINES WITH DIFFERENT CONCENTRATIONS OF HYDROCHLORIC ACID

Amine	Millimoles of HCl added to the amine solution	Average value of K_0
p-Toluidine	1	0.484 (after 300 minutes)
p-Toluidine	1.5	8.99 > 4.39, (See Table I)
p-Toluidine	2	20.9
p-Toluidine	6	33.5
o-Chloroaniline	2	83.5
o-Chloroaniline	3	127.5
o-Chloroaniline	6	241.5
o-Chloroaniline	10	304.5
p-Chloroaniline	2	64.5
p-Chloroaniline	6	76.5
p-Chloroaniline	10	79.1
m-Chloroaniline	2	22.9
m-Chloroaniline	6	67.5
m-Chloroaniline	11	90.8
o-Aminobenzoic acid	0	0.261 (120′), 0.135 (300′)
o-Aminobenzoic acid	0.25	See Table II
o-Aminobenzoic acid	.5	22.7
o-Aminobenzoic acid	1	54.9
o-Aminobenzoic acid	2	162
o-Aminobenzoic acid	3	418
o-Aminobenzoic acid	6	881

1\. *p*-Toluidine + 1.5 mml. HCl

After min.	% Amine inverted	K_0
25	31.0	8.99
40	41.4	8.83
60	51.0	8.67
90	58.1	7.70
130	62.0	6.28
198	67.3	5.20
300	72.5 (50 + 22.5)	4.39

2\. *o*-Aminobenzoic acid + 0.25 mml. HCl

After min.	% Amine inverted	K_0
10	9.6	5.31
22	19.1	5.37
30	23.9	5.23
40	29.5	5.23
55	34.2	4.73
70	37.6	4.30
110	40.5	3.09
300	49.5	1.63

3\. *m*-Chloroaniline + 11 mml. HCl

After min.	% Amine inverted	K_0
2	26.8	91.5
5	48.0	92.3
6	52.1	90.6
8	59.1	90.0
10	64.5	90.9
20	78.3	90.2
40	88.0	91.7
70	92.6	89.4
141	96.4	..
370	100.0	..
		Average 90.8

This solution is obtained by adding 44 cc. of 0.2 *N* sodium hydroxide to 50 cc. of a solution of Schäffer salt containing 6 g. per liter, diluting the mixture afterward to 100 cc. Five cubic centimeters of the colored solution obtained after coupling at 0° is diluted to 500 cc. with distilled water and compared in a colorimeter of Wolff. Beer's law did hold good, and assuming the last sample taken after six hours to represent 100% we compared this standard solution in the colorimeter with the colors obtained from the samples after two, four, six, eight, etc., minutes. Thus we could read in a direct way the percentage of diazotized amine. Also it should be mentioned that we used distilled water for all the experiments as tap water possessed too much color of its own.

In the experiments sodium hydroxide has been added to the Schäffer salt solution in accordance to the extra addition of hydrochloric acid mentioned in the table of the constants of reaction velocities.

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Summary

1\. The velocity of the diazotization reaction is not inversely proportional to the excess of hydrochloric acid ($b - 2a$); therefore the reaction does not take place between free amine and nitrous acid.

2. It must be concluded, especially from the results with small concentrations of hydrochloric acid, that the reaction proceeds between the salt of the amine (*pentavalent* nitrogen) and nitrous acid.

3. No agreement has been obtained with the *calculated* velocity for this case. Mostly the influence is much more than can be accounted for by decreasing hydrolysis of the salt of the amine.

4. The excess of hydrochloric acid increases the velocity of diazotization for all the amines which were investigated, by (1) decreasing hydrolysis of the salt of the amine; and (2) a specific action.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE UNIVERSITY OF KENTUCKY]

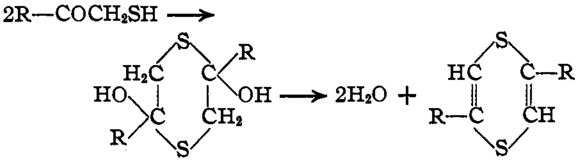
The Preparation of 1,4-Dithienes

BY ROBERT H. BAKER AND CHARLES BARKENBUS

The preparation and chemistry of compounds containing the 1,4-dithiene ring structure have never been thoroughly investigated. Steude,[1] prepared this type of ring structure by hydrolyzing ethyl thioacetoacetoacetate. The yields of 2,5-dicarbethoxymethyl-1,4-dithiene were very small, and though attempts to improve the yields were made, no successful method was discovered. Tcherniac[2] obtained 2,5-dimethyl-1,4-dithiene as a by-product in the hydrolysis of thiocyanoacetone while Levi[3] synthesized 1,4-dithiene, the mother substance of this series, by heating thiodiglycolic acid with phosphorus trisulfide though again the yields were very small. Johnson[4] by hydrolyzing 2-benzoylmethylmercapto-4-methyl-6-oxypyrimidine obtained 2,5-diphenyl-1,4-dithiene instead of the expected phenacyl mercaptan. Groth[5] by the hydrolysis of phenacyldithiocarbaminoacetic acid prepared for the first time a β-ketomercaptan, namely, phenacyl mercaptan, and condensed this to 2,5-diphenyl-1,4-dithiene though no yields were given.

Our knowledge of the chemistry of this type of ring structure is practically non-existent. Levi was able to show that the Friedel and Crafts reaction is possible with 1,4-dithiene, while Johnson and co-workers nitrated 2,5-diphenyl-1,4-dithiene although the nature of the product obtained was not investigated. Groth has also shown that 2,5-diphenyl-1,4-dithiene will form addition products with phenacyl mercaptan. Apparently a characteristic reaction for this type of ring structure is the intense red color produced when these compounds are dissolved in concentrated sulfuric acid, the color disappearing upon dilution.

The literature indicates that the most logical approach to this type of structure is through the condensation of β-keto mercaptans and the purpose of this work was to investigate the effect of different groups on this condensation. The condensation can be pictured as taking place according to the following equation although condensation through enolization would lead to the same product.



It has been observed that R must be an aryl group if ring formation as shown above is to take place to any extent. Preliminary work has indicated that if R is a methyl group other types of condensation take place in a manner similar to the condensation of acetone to mesityl oxide and phorone.

Phenacyl mercaptan, described by Groth, is the only β-keto mercaptan described in the literature and the method of synthesis is far from practical. It is an unstable oil which readily undergoes further changes when exposed to the air. The most direct method of preparation would be the action of sodium acid sulfide on β-keto halides but this procedure gives the sulfides as the main product.[6]

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(1) Steude, *Ann.*, **261**, 45 (1891).

(2) Tcherniac, *J. Chem. Soc.*, **115**, 1071 (1919).

(3) Levi, *Chem. News*, **62**, 216 (1890).

(4) Johnson, Moran and Kohmann, THIS JOURNAL, **35**, 447 (1913).

(5) Groth, *Arkiv. Kemi. Mineral. Geol.*, **9**, No. 1, 63 (1924).

(6) Tafel and Mauritz, *Ber.*, **23**, 3474 (1890).