thesia was obtained with both subjects, lasting for 15 to 20 minutes. These results indicate the pronounced and characteristic pharmacological properties of these two compounds and show that the imido-ester grouping possesses much greater local anesthetic action than the plain diethylamino-ethyl ester of diphenic acid.

Summary

1. Diphenylchloride and the imide chloride of diphenanilide both react smoothly with diethylamino-ethyl alcohol, $(C_2H_5)_2NCH_2CH_2OH$, to form the corresponding ester and imido ester, respectively.
2. Both of these compounds have been tested pharmacologically and the preliminary tests have been very satisfactory, revealing the characteristic property of producing local anesthesia in both cases.
3. An attempt to reduce the imide chloride of diphenanilide to the corresponding aldehyde by reduction with stannic chloride in ether solution was unsuccessful.
4. The study of diphenic acid derivatives will be continued.

New Haven, Connecticut

[Contribution from Kent Chemical Laboratory, University of Chicago]

CATALYTIC TRANSMUTATION OF MALEIC ACID INTO FUMARIC ACID[1]

By Ethel M. Terry and Lillian Eichelberger[2]

Received November 3, 1924 Published May 5, 1925

One of the curious enigmas of the chemistry of maleic acid is that this acid can undergo transmutation to fumaric acid under the influence of a catalyst such as bromine without adding the catalyst at the double bond, and yet in order to have undergone such a transmutation, the double bond of maleic acid must have passed through an active phase during which the double bond should add bromine very easily. The present paper reports measurements of the rate of transmutation of maleic acid in water solution under the influence of certain catalysts, and gives a theory of the process of transmutation deduced from these measurements. It will be shown that the mechanism suggested by the theory accounts for the above-mentioned phenomena. The catalysts employed in the experimental work reported are hydrobromic acid, hydrochloric acid and potassium thiocyanate, respectively.

Measurement of Rates of Reaction.—The measurements of rates of transmutation were carried out as follows. Samples of a given solution

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[1] Presented by title at the April Meeting (1924) of the American Chemical Society.

[2] The experimental work of this paper was carried out by Lillian Eichelberger in fulfilment of part of the requirement for the degree of Doctor of Philosophy at the University of Chicago, 1921.

of maleic acid and catalyst were sealed in Pyrex tubes which were then immersed for selected intervals in a boiling water-bath (99.2°), the temperature of which was constant to 0.1°. At the proper moments the tubes were quickly withdrawn, plunged into chopped ice and shaken for an hour. They were then opened and the concentration of unused maleic acid was determined as will be described later. The results of two experiments are given in detail in Table I. Summaries of all experiments are given in Table II. The titles of columns in Tables I and II are self-explanatory except the term "*kc*." The latter is the apparent coefficient

TABLE I

EXAMPLES OF MEASUREMENTS OF RATES OF TRANSMUTATION OF MALEIC ACID TO FUMARIC ACID

A. HYDROBROMIC ACID (2.150 *N*) CATALYST

Bath temp., 99.2°

No.	Molar concn. of maleic acid	Time Minutes	Titrations used to calculate *kc*		*kc*
0	0.315	0	1–4		0.0031
1	.308	67	2–4		.0032
2	.291	127	3–4		.0033
3	.274	201	1–3		.0030
4	.238	372	2–3		.0030
			1–2		.0030
				Av.	.0031

B. POTASSIUM THIOCYANATE CATALYST (0.0569 *N*)

Bath temp., 99.2°

No.	Molar concn. of maleic acid	Time Minutes	Titrations used to calculate *kc*		*kc*
0	0.668	0	1–5		0.0062
1	.604	30	2–5		.0062
2	.551	60	3–5		.0062
3	.388	180	4–5		.0063
4	.279	346	2–4		.0062
5	.214	520	1–4		.0061
			3–4		.0060
				Av.	.0062

TABLE II

SUMMARY OF EXPERIMENTS

Catalyst	No.	Concn. of catalyst in moles per liter	Concn. of maleic acid in moles per liter	*k*
Hydrobromic acid	1	2.150	0.315	0.0015
	2	2.997	.336	.0029
	3	3.856	.354	.0061
Hydrochloric acid	1	2.228	.329	.0017
	2	2.977	.734	.0015
Potassium thiocyanate	1	0.2210	.385	.120
	2	.0924	.692	.110
	3	.0924	.692	.115
	4	.0569	.668	.109

of the reaction and is equal to the true coefficient of the reaction, *k*, multiplied by the concentration of the catalyst, *c*. The methods for calculating *kc* and *k* are given below.

It was next shown that when excess fumaric acid was put in the initial reaction mixture no effect on the rate of reaction could be observed, and that no appreciable quantity of by-products was formed during the reaction. It was also shown that an increase of the specific surface of the solution had no effect.

The Equation Representing the Rate of Reaction

The usual method of trial and error was employed to discover the function that should describe the rate of change. A very simple expression was found to be applicable. In this, the rate of the reaction depends on the first power of the concentration of the catalyst, and on the second power of the concentration of maleic acid, as represented by the following: $dx/dt = k(a-x)^2\ (c)$, where x represents the concentration of fumaric acid formed at any interval of time t, a represents the initial concentration of maleic acid, and c the concentration of the catalyst which is a constant quantity throughout a given experiment. In Table II, the last column gives the true coefficient (k) of the reaction. The integrated form of the above differential expression for the interval betewen t_1 and t_2 is,

$$kc = \frac{1}{t_2 - t_1}\left[\frac{1}{a - x_2} - \frac{1}{a - x_1}\right]$$

In the case of hydrobromic acid the coefficient k changes with increase in the concentration of catalyst, as is indicated by the steady increase in value given in the last column. In the experiments with potassium thiocyanate and in the two examples of catalysis with hydrochloric acid reported, the coefficient is constant.

Discussion of the Equation.—In reference to the second order equation given, it was obvious that if any substance like malic acid were accumulating in the solution during the reaction so that the reported concentration of the maleic acid were in reality too high, or if fumaric acid had a retarding influence on the reaction, the relationship indicated by the equation would be illusory and the real order of the reaction might be unimolecular with respect to the concentration of maleic acid. Hence, as has already been stated, the non-existence of these factors was carefully established.

In as much as the same function governs both catalysis by potassium thiocyanate and by hydrochloric and hydrobromic acids, it seemed futile to search for an expression in which one of the ions of maleic acid or the hydrogen ion is made an active factor. In reference to the first suggestion, the well-known indifference of the salts to transmutation confirms the conclusion.

That a function which is bimolecular with respect to the concentration of maleic acid should govern the change revived interest in a possible polymeric formula for fumaric acid. However, maleic anhydride,[3] diethyl fumarate,[4] and *l*-bornyl fumarate[5] have been shown to have molecular weights corresponding to a unimolecular formula. The molecular weight of dimethyl fumarate was measured by us, by the Victor Meyer method and was found to be that of the single molecule. The fact that the esters of maleic and fumaric acid contain single $C_4H_2O_4$ groups indicates that the maleic and fumaric acids are not polymeric forms one of the other, for the esters are easily hydrolyzed by aqueous alkali to form the salts of the corresponding acids and, furthermore, in addition reactions of the double bond esters behave as do the acids. Therefore, the fact that the equation describing the change contains the concentration of maleic acid to the second power could not be interpreted to mean that a polymerization was in progress.

Calculations of the degree of ionization of maleic acid and of fumaric acid at the concentrations used in the experiment were made on the basis of the coefficients of ionization given by White and Jones[6] for 25°. These authors have shown that the variation of the coefficients with dilution or with rise of temperature is not large, so that it may be supposed that the calculated values of the degree of dissociation are not far from the true ones for the temperature of the experiment. The degree of ionization of maleic acid from time to time in the reaction mixture was then estimated, taking into consideration the effect of the accumulating fumaric acid. These results show that the concentration of the non-ionized maleic acid is in all probability nearly proportional (within 10%) to the total concentration of maleic acid throughout the experiments in question in the case of potassium thiocyanate. Therefore, the probable interpretation of the term "total maleic acid concentration squared" is "total non-ionized maleic acid concentration squared." The same interpretation is obvious for the cases of catalysis by hydrochloric acid and hydrobromic acid.

Considering now the reported coefficients, *k*, Table II, it is obvious that one reason for the lack of constancy of this term in the case of experiments with hydrobromic acid is that new units such as $(HBr)_2(H_2C_4H_2O_4)$ become active at greater concentrations but that our methods of analysis do not admit of their detection. In addition, however, other points should be considered. It has already been shown by others[7] that in the cases of hydrolysis of cane sugar or of esters, if a function is to describe the rate of a reaction over a wide range of concentration, then the concentrations

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[3] Hübner and Schreiber, *Z. Chem.*, [2] **7**, 712 (1871).

[4] Ossipoff, *Bull. soc. chim.*, **50**, 137 (1889). He states that the diethyl fumarate and maleates and *iso*propyl maleate and fumarate have normal vapor densities except that the last named shows some sign of decomposition at the temperatures of measurement.

[5] McKenzie and Wren, *J. Chem. Soc.*, **91**, 1215 (1907).

[6] White and Jones, *Am. Chem. J.*, **44**, 159 (1910).

[7] See, for example, Kendall, THIS JOURNAL, **36**, 1069 (1914).

of the reacting components may not be represented in terms of moles per unit volume of solution, but should be put in moles for unit volume of solvent or, better, in terms of mole fraction. However, in solutions as concentrated as those described here, we are in doubt as to just what may be called the solvent. The water present can hardly be so considered in the case of the strong acid solutions. In each separate experiment, since at the temperature used fumaric acid remains in solution, the solvent remains constant, and the function which should be used to convert volume of solution into volume of solvent or to transform concentration into mole fraction is included in the observed velocity coefficient. On this account, the simple expression given above fits the results of experiment over the small ranges of concentration represented. It is not to be expected that it should hold over wide ranges of hydrogen chloride concentration though it seems to do so in the two cases tried. (It is of interest that the apparent coefficient of the change is the same for these and for the dilute hydrobromic acid mixtures. This seems to reflect a hydrogen-ion catalysis.) The factors governing rates of reaction in concentrated solutions are so complex that further effort was not made to secure a more general function. That where solvent effects are uniform as in the thiocyanate catalysis or the single experiments with the strong acids, the reaction is a function of the second power of the maleic acid concentration and the first power of the catalyst concentration, a critical point in the chemistry of the isomeric acids under consideration, will now be shown.

Older Theories.—The reader will at once be reminded of Stewart's theory of the process of transmutation since this theory would make the reaction proportional to the second power of the concentration of maleic acid. In brief, he assumes that two molecules collide, thus bringing the two double bonds together with the result that "this collision so disturbs the internal equilibrium that when the molecules separate they split apart so as to form two others of a stable type."[8] However, he does not attempt to account for the role of the catalyst.

Michael[9] has represented the change as involving many molecules of maleic acid and one of catalyst but without assigning any definite ratio of one to the other.

Mechanism of the Reaction.—It is possible with data now available to assign a definite reason for the function under discussion. It has long been recognized that the failure of maleic acid to change to fumaric acid at ordinary temperatures even in the presence of sunlight (except extremely slowly) must be ascribed to some special resistance to change. To what may this undue stability be ascribed?

[8] See Stewart's book "Stereochemistry," Longmans, Green and Company, **1907**, p. 189, for the best description of his theory.

[9] Michael, *Am. Chem. J.*, **39**, 3 (1908).

If the chemistry of the geometric isomers is reviewed it will be found that unless there are unsaturated groups attached at one or both of the carbon atoms of the double bond only a slight difference in properties is found. When, however, there is an unsaturated group on either or both of the carbon atoms of the double bond, then marked differences are observed, and they are greater in the second case than in the first. The chemistry of the geometrical isomers as it is generally understood is virtually that of these two types.

We may, therefore, ascribe the undue stability spoken of above to the presence of the unsaturated groups and assign to them a certain influence which must be removed before activation of the double bond is possible. This basic idea is strengthened by the observation of many chemists that the rate of bromination of the double bond is materially lessened by the presence of unsaturated groups attached to one or both of the carbon atoms of the double bond.[10] Furthermore, ease of halogenation is apparently accompanied by ease of transmutation. Thus *iso*crotonic acid, which is much more rapidly acted upon by halogens than is maleic acid, undergoes transmutation at temperatures at which maleic acid is entirely stable, etc. Hence, the fundamental idea is in accord with the general facts.

In the case of α,β-unsaturated carboxylic acids, any reagent that is capable of saturating the carboxyl groups should favor transmutation. As is well known from the work of McIntosh[11] and Maass,[12] strong acids are capable of such effects, but in addition it should be possible to employ a great variety of reagents. This is in accord with what is known about agents for catalysis of the transmutation in question.

In the case of maleic acid two carboxyl groups must be taken care of as a preliminary to transmutation. Hence, two catalyst molecules must be involved with every molecule of maleic acid which undergoes change and the reaction should be of tertiary degree. (This should not be the case, for example. with *iso*crotonic acid when it undergoes transmutation since this acid has only one unsaturated group attached to the double bond.)

Under the conditions reported in this paper maleic acid itself functions as one of the catalyst molecules. Presumably the double bond of one molecule saturates the carboxyl of another. The first molecules thus should be rendered extremely stable. If the second molecule then picks up another catalyst molecule at the remaining carboxyl group, the obstructive influence of the two carboxyl groups will have been removed.

The formation of the active unit may be pictured as follows (X represents the catalyst molecule).

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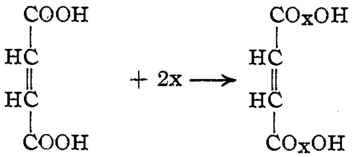
[10] Bauer, *Ber.*, **37,** 3317 (1904); *J. prakt. Chem.*, **72,** 201 (1905). Bauer and Moser, *Ber.*, **40,** 918 (1907). Meyer, *Ann.*, **398,** 66 (1913). See also Plotnikow's excellent review, "Allgemeine Photochemie," **1920,** pp. 384, 476.

[11] McIntosh, THIS JOURNAL, **36,** 737 (1914).

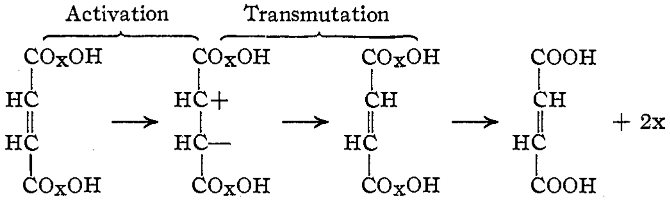
[12] Maass, *ibid.*, **33,** 71 (1911).



$$\begin{array}{c}COOH\\ |\\ HC\\ \|\\ HC\\ |\\ COOH\end{array} + 2x \longrightarrow \begin{array}{c}CO_xOH\\ |\\ HC\\ \|\\ HC\\ |\\ CO_xOH\end{array}$$

The concentration of these active complexes should be small at any moment, and their capacity for the absorption of energy should differ according to the nature of x, so that the rate of transmutation of maleric acid with different catalysts should be different.

The actual transmutation should be pictured as occurring as the result of the formation of an active form of the double bond which for the present can best be represented as an electromer, thus.



$$\overbrace{\begin{array}{c}CO_xOH\\ |\\ HC\\ \|\\ HC\\ |\\ CO_xOH\end{array} \longrightarrow}^{\text{Activation}} \overbrace{\begin{array}{c}CO_xOH\\ |\\ HC+\\ |\\ HC-\\ |\\ CO_xOH\end{array} \longrightarrow}^{\text{Transmutation}} \begin{array}{c}CO_xOH\\ |\\ CH\\ \|\\ HC\\ |\\ CO_xOH\end{array} \longrightarrow \begin{array}{c}COOH\\ |\\ CH\\ \|\\ HC\\ |\\ COOH\end{array} + 2x$$

This stage of the change (transmutation) has been in the minds of many chemists.[13] The new idea is that saturation of the carboxyl groups greatly increases the opportunity for the formation of the active phase of the double bond.

It is here suggested that the explanation of the mathematical function found to describe the rate of transmutation of maleic acid into fumaric acid under the influence of a catalyst is that this function describes the rate of activation of a molecule of maleic acid which is holding two other molecules at its carboxyl groups. In other words, the stage marked "activation" in the above reaction is the slowest of the stages and is the one measured. At any instant of time the concentration of the reacting molecule is dependent on the square of the concentration of maleic acid and on the first power of the concentration of the catalyst (since the concentration of the active unit is relatively small). Such a change should be sensitive to heat and to light of suitable wave length and this is true of the changes in question.

The rate of formation of the saturated maleic acid would, of course, be described by the same type of equation. This is an alternative explanation made after the manner of W. C. McC. Lewis and of S. Dushman.[14]

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[13] For recent discussions see: Lewis, "Valence and the Structure of Atoms and Molecules," **1923.** Lowry, *J. Chem. Soc.*, **123,** 822 (1923). Noyes, THIS JOURNAL, **45,** 2959 (1923). Carothers, *ibid.*, **46,** 2226 (1924).

[14] Best summarized on p. 1030 and following in the article by Dushman in "A Treatise of Physical Chemistry" edited by Taylor, **1924.** See also the latter's comment in the footnote of p. 1036.

Since the detail of the picture of the process of transmutation becomes involved if this mechanism is adopted, for the present we prefer to use the first explanation given as the graph of the process of the reaction. Either explanation would correlate the degree of the equation for the rate of the reactions in question with the necessity of removing the obstructing influence of the two carboxyl groups, and this is the critical point offered.

The rate of transmutation of the electromer also would be described by the same type of equation as the mechanisms cited above. However, since at this point there should be a minimum of restraint, the change should be effected instantaneously. Therefore, of the possible stages the activation of the saturated complex as already stated is considered the change measured.

We shall next show that the mechanism described accounts for the most striking fact of the catalytic transmutation under consideration, namely, that the maleic acid can undergo transmutation without concomitant addition at the double bond. According to the suggested mechanism, the same complex that is active in transmutation may be active in addition. In the case of hydrobromic acid, for example, the first molecule of this catalyst is pinned at the carboxyl and so is out of range of the double bond during the latter's active phase. If another molecule of catalyst should arrive during this phase, addition at the double bond should occur. In our experience with hydrochloric and hydrobromic acids, no appreciable addition of hydrogen halide took place, but had we used the fuming acids we would have secured a product consisting of half fumaric acid and half halogen succinic acid.[15]

Another way of stating the above is that the suggested mechanism makes transmutation of maleic acid an apparently trimolecular reaction, and the addition of a hydrogen halide at the double bond of maleic acid an apparently tetramolecular reaction. This deduction agrees with the results of experiment, namely, that dilution retards the addition reaction more than it does the transmutation reaction, since this indicates that the first reaction is of a higher order than the second.

The same type of phenomenon is found when aqueous solutions of maleic acid are treated with bromine. Petri[16] has shown that if a very concentrated solution of maleic acid is treated with an equivalent of bromine, *iso*dibromo-succinic acid forms, together with considerable fumaric acid (27% of the yield). On the other hand, Wislicenus[17] has shown that if a solution of maleic acid is treated with small quantities of bromine in sunlight, nearly exclusive transmutation of maleic acid to fumaric acid

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[15] Fittig, *Ann.*, **188**, 91 (1877).

[16] Petri, *Ann.*, **195**, 61 (1879).

[17] Wislicenus, *Chem. Zentr.*, **68**, **II**, 259 (1897). See also Weiss and Downs, THIS JOURNAL, **44**, 1118 (1922).

takes place. When we consider the usual behavior of bromine and ethylene in sunlight, it seems indeed remarkable that maleic acid can pass through an active phase in the presence of bromine without adding it to the double bond and it is important that the above mechanism accounts for this phenomenon.[18]

Validity of the Theory Presented

The above theory cannot be said to have been proved to be true. However, it correlates the highly diverse facts known of the reaction under consideration on a consistent basis and is therefore presented.

Experimental Detail

Materials.—Maleic acid was obtained by dissolving maleic anhydride in water. The anhydride was first prepared from commercial malic or maleic acid by the acetyl chloride method of Anschütz.[19] This method was later abandoned for the phosphorus pentoxide method[20] described elsewhere. The anhydride was recrystallized from chloroform and its purity tested both by weight titration and by melting point. Fumaric acid was purified by recrystallization from hot water. In a sealed tube it melted at 280°. Its purity was checked by weight titration. C. P. hydrochloric acid (d., 1.2) was diluted with one volume of water and distilled. The constant-boiling portion was used. C. P. hydrobromic acid (fuming) was diluted with one volume of water and distilled over ferrous sulfate. The constant-boiling distillate was used. Potassium thiocyanate was purified by the method of Jones.[21]

Standardization of Reagents.—The concentration of hydrochloric acid was determined by the silver chloride precipitation method. Sodium hydroxide, free from carbonate, was used for titrations, and its concentration determined by reference to standard acid. The concentration of hydrobromic acid was obtained by titration with standard base. Phenolphthalein was used as indicator in these experiments. Silver nitrate solutions were standardized by the gravimetric silver chloride method. The concentration of potassium thiocyanate solutions was determined by titration with silver nitrate, using ferric sulfate as indicator in the well-known way.

Analysis of Samples.—The concentration of unchanged maleic acid present in

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[18] Bruner and Krolikowsky [(a) *Bull. inter. Acad. Sciences,* (Krakow) **1910A,** p. 192] have shown that when maleic acid in dilute water solution (0.01 *M*) is treated with an equivalent of bromine in the presence of mineral acids, the rate of the reaction is dependent on the first power of the concentration of maleic acid, and the first power of the concentration of bromine, and is inversely proportional to the concentration of the mineral acid. The product of this reaction is chiefly a mixture of the isomeric dibromosuccinic acids and the probable significance of the equation is that the acid ion of maleic acid ($HC_4H_2O_4^-$) is undergoing change. Thus, this evidence has no bearing on the bromination of maleic molecules. These authors also state that the transmutation of maleic acid under the influence of sunlight and bromine follows the unimolecular law as long as the concentration of bromine is kept very small. Since they make no study of the effect of stirring on the rate of change, it seems probable that they really measured a diffusion effect.

[19] Anschütz, *Ber.,* **12,** 2281 (1879).

[20] Terry and Eichelberger, THIS JOURNAL, **47,** 1067 (1925). Bogert and Ritter, *ibid.,* **47,** 526 (1925).

[21] Jones, "Conductivity and Viscosity," **1915,** p. 181.

samples collected as already described was determined by titration of 4cc. portions after the fumaric acid had been precipitated[22] at 0°.

For the work with hydrochloric and hydrobromic acids, the total acid content was determined by titration with standard sodium hydroxide solution. The difference between the total acid concentration and the catalyst acid concentration gave the concentration of the maleic acid in solution, uncorrected for the solubility of fumaric acid at 0°. Separate experiments showed that this correction was too small to be considered.

The hydrochloric or the hydrobromic acid content of the reaction mixture was determined as follows. Four cc. lots of the filtered reaction mixture were measured at 25°. To each about 20 cc. of water and an excess of known volume of standard silver nitrate were added. The precipitated silver halide was removed. The excess of silver nitrate in the filtrate was determined by the Volhard method of titration against standard potassium thiocyanate with ferric nitrate as indicator.

In the work with potassium thiocyanate the titration of the filtrates from the fumaric acid crystals gave at once the concentration of the maleic acid. However, a correction for the solubility of fumaric acid had to be applied and this was supplied from the data from separate experiments on the solubility of fumaric acid in mixtures equivalent to those analyzed in measurements of rates of reaction. The potassium thiocyanate content of the reaction mixtures was determined in the same way as was that of the hydrochloric and hydrobromic acids except that a small quantity of nitric acid was added to the mixture.

The correctness of the methods of the above analysis was confirmed by carrying them out with mixtures of known composition and near in value to those of our experiments.

Absence of By-Products.—The concentration of the catalyst was determined at the beginning and end of each experiment, and was found not to have changed more than 3% at most, so that no appreciable addition of catalyst at the double bond could have occurred. There was also the possibility of malic acid forming, so that it was necessary to develop a special test for this acid. This is given below. However, only traces of malic acid were found in any of the reaction mixtures. We were, therefore, confident that no appreciable quantity of by-products formed during the change measured.

Detection of Malic Acid.—A qualitative test for malic acid is made as follows. To a given solution containing malic acid add, drop by drop, 0.5 cc. of a 0.2 *M* solution of titanium tetrachloride in absolute alcohol.[23] When malic acid is present, a white crystalline precipitate of $2TiO_2.C_4H_6O_5.6H_2O$ appears in a few minutes. In the reaction mixtures in which hydrogen chloride or hydrogen bromide was present, it was found necessary to neutralize these acids with an exact equivalent of base before completing the test. The mixture was then cooled to room temperature and the titanium tetrachloride added, etc. Tests made on mixtures of known composition showed that the results could be relied on for concentrations of malic acid as low as 0.5% of the initial maleic acid.[24]

Summary

The rates of transmutation of maleic acid in water solution at 99.2° under the influence of hydrobromic acid, hydrochloric acid and potassium thiocyanate, respectively, have been measured and have been shown to

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[22] We have since learned that Bruner and Krolilowsky (Ref. 18 a) used this method.

[23] Berg, *Z. anorg. Chem.*, **15**, 328 (1897).

[24] A quantitative determination of malic acid in the presence of maleic and fumaric acids, by the use of this reagent, has been worked out in connection with a study of the rate of hydration of maleic acid and will be reported with that study.

depend, under limited conditions, on the first power of the concentration of the catalyst and on the second power of the concentration of maleic acid. A theory of the reaction is given which is in accord with the present known facts of the transmutation of maleic acid to fumaric acid.

Chicago, Illinois

[Contribution from Kent Chemical Laboratory, University of Chicago]

OXIDATION OF FUMARIC AND OF MALEIC ACID TO TARTARIC ACID[1]

By Nicholas A. Milas[2] and Ethel M. Terry

Received November 12, 1924 Published May 5, 1925

The recent success of Messrs. Weiss and Downs[3] in making fumaric and maleic acids easily available directed our interest to the production of racemic and *meso*tartaric acids from these sources.

Of the methods reported in the literature, namely, bromination and subsequent hydrolysis,[4] oxidation with permanganate,[5] or oxidation by a mixture of potassium chlorate and osmium[6] tetra-oxide, the latter was chosen for intensive study, since preliminary experience with the others had shown the existence of serious limitations in their use. K. A. Hofmann, who first reported the osmium tetra-oxide method, states that he recovered 7 g. of primary sodium tartrate (monohydrate) and 4 g. of calcium racemate (tetrahydrate) as a result of the reaction of 10 g. of fumaric acid with 5 g. of sodium carbonate, 12 g. of sodium chlorate and 0.02 g. of osmium tetra-oxide in 100 cc. of water for six to ten hours at 40°. From the reaction of a similar mixture in which the fumaric acid was replaced by maleic acid, 16 g. of calcium mesotartrate (trihydrate) was recovered. The first result represents 60% of the tartaric acid theoretically possible, and the second, a 72% yield. In each instance, the sodium carbonate was sufficient in amount to convert the initial acid into the acid salt.

It seemed probable that the method could be improved since no extensive study had been reported by Hofmann and since the loss through side action should be a function of the hydrogen-ion concentration. This proved to be the case. We herewith report an improved method by which 97+% yield of the respective acids may be obtained under conditions which are practical for the average preparative laboratory.

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[1] Presented by title at the Organic Division of the Convention of the American Chemical Society, April, 1924.

[2] The principal part of the experimental work of this paper was completed by Nicholas A. Milas in fulfilment of part of the requirements for the degree of Master of Science at the University of Chicago, 1923.

[3] Weiss and Downs, *J. Ind. Eng. Chem.*, **12,** 228 (1920).

[4] Lossen, *Ann.*, **300,** 24 (1898).

[5] Kekulé and Anschütz, *Ber.*, **13,** 2150 (1880).

[6] Hofmann, Ehrhart and Schneider, *Ber.*, **46,** 1667 (1914).