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REPORT

of

COMMITTEE ON EXAMINATION

This is to certify that we the undersigned, as a Committee of the Graduate School, have given **Everett Haisley Doherty** final oral examination for the degree of Master of **Science**. We recommend that the degree of Master of **Science** be conferred upon the candidate.

Minneapolis, Minnesota
May 28 1917

RA Gortner
Chairman
J. H. Dinby
FJ Alway

REPORT

on

COMMITTEE ON THESIS

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Everett Haisley Doherty for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

Minneapolis, Minnesota
May 28 1917

R A Gortner
Chairman

F J Alway

A PHYSICO - CHEMICAL STUDY OF THE GLUTEN OF STRONG AND WEAK FLOURS.

By Everett H. Doherty

A THESIS
Submitted to the Graduate School of the University of
Minnesota in partial fulfillment of the requirements
For the Degree
of
Master of Science.

St. Paul, Minnesota
May 18, 1917.

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I -INTRODUCTION

Historical. The change in state of colloids brought about by acids, bases, and salts is of great practical importance, not only in the industries, in dyeing, in tanning, in treatment of sewage, in purification of water, in mining, in chemical technology, but also in therapeutics and physiology.

The colloidal swelling of proteins has been extensively studied by Hofmeister (1890), Pauli (1897 and 1898), Spiro (1904) Ostwald (1905), Fisher (1915) and Hardy (1900).

In working on the problem of the correlation between chemical composition and baking qualities of flour, T.B. Wood (1907) after experimentation with many different flours in which their CO_2 production during fermentation was measured; came to the conclusion that there were two factors which effected the baking strength of flours; (1) the factor which affected the size of the loaf and, (2) the factor which effected the shape of the loaf.

His earlier investigations showed that the first factor the size of the loaf, was directly connected with the rate at which CO_2 was produced during the later stages of dough fermentation, when it was ready for the oven. This depends upon the fermentable sugars which occur in the flour or which are added at the time of making the sponge. In other words, this factor depends upon the chemical composition of the flour.

In his attempts to find the factors which affect the shape of the loaf, he determined the total nitrogen, total gliadin nitrogen, total ash, total soluble ash, and acid in several different flours. As a result of these analyses he arrived at the conclusion that there was no correlation between any of these results and the baking strength of flour with the possible exception of a slight correlation between the baking strength and the relation of soluble ash to total nitrogen. From this he concluded that the shape of the loaf must depend upon the physical properties of the flour rather than upon chemical factors.

He showed that the protein complex, wheat gluten, was a typical emulsoid colloid and that its state depends entirely upon the concentrations of acids, bases and salts in which it is placed. This confirms the work of Picton and Linder (1905) and of Hardy (1900) in their study of the effect of electrolytes upon colloids.

At the suggestion of Hardy, Wood began his investigations on the physical properties of gluten, especially on the effect of different kinds of solutions upon its physical state.

It had been previously observed that there was considerable variation in the character of gluten prepared from different samples of flour. When the starch from various flours is washed out under a stream of distilled water, gluten, varying from a sticky, friable, somewhat gummy mass to a coherent rather firm aggregate is obtained. Wood carried on his studies by suspending strings of gluten about the size of a pencil across V-shaped glass rods in beakers containing varying concentrations of different acids and "noting the concentration at which cohesion was so far reduced as to allow the protein to fall off of the rod and disperse in a cloudy solution."

In this manner it was found that gluten suspended in pure distilled water retained its coherence almost indefinitely, but that in solutions containing as little as N/1000 hydrochloric acid, "disintegration" began to take place almost immediately. At higher concentrations up to about N/30 this action increased to a maximum and then the gluten began more and more to retain its properties until a N/12 solution was reached, where it was found to be more coherent and elastic than it was in the original condition.

Maximum hydration concentrations were also found for other acids -- sulphuric, phosphoric, acetic, lactic, oxalic, citric and tartaric, though this was found to vary with the different acids, and at higher concentrations the swelling becomes less.

Upson & Calvin (1915) attempted to measure the "hydration capacity" of gluten in a more exact manner than that of Wood and Hardy. They found that moist gluten loses water in N/2 and N/5 hydrochloric acid and becomes a resistive tough coagulum.

Ostwald (1905) found the order in which different acids cause gelatin to swell, to be, hydrochloric > nitric > acetic > sulfuric > boric.

The effect of soluble salts in the various concentrations is to decrease the amount of swelling. This was first observed by Wood. He found that, when added in sufficient amounts, salt would entirely inhibit the imbibition of water. Increasing amounts of salt were required up to the optimum swelling concentration of the acid and then decreasing amounts. Wood presents this very clearly in a series of graphs. Different salts were found to have differing inhibition properties. The chloride and phosphate of sodium were found to be approximately equal, the chloride being somewhat more active with higher concentrations of acid and the phosphate at lower concentrations. Sodium sulphate is more effective than either chloride or phosphate, the ratio of the chloride and phosphate: sulphate being approximately 2:3. Experiments with salts having the same anion or acid radical combined with different metals with varying valences, showed that effectiveness increased with valency. For this reason equi molar solutions of different salts do not diminish water absorption equally. Fischer & Sykes (1913), (1914) demonstrated the interesting fact that non electrolytes, e.g. sugar, alcohol and urea, produce a much less inhibiting effect on water absorption by gelatin in acid and neutral solution than do neutral salts.

Upson & Calvin (1915) employed the method first used by Hofmeister (1901) in his investigations on swelling of animal proteins. In their experiments the gluten was first freed from starch by washing in a stream of distilled water. It was then pressed out between glass plates to a fairly uniform thickness and after standing for some time, was cut into small discs. These discs were weighed to the nearest centigram, placed in beakers containing acid solutions of varying concentrations and allowed to remain for a constant period of time. They were then removed, drained, and reweighed. The increase in weight due to imbibition of water was calculated to the amount absorbed per gram of moist gluten. The experiments were then repeated except that a series of salts were added to the different concentrations of the acids. The addition of the salt caused a diminution of the water absorption. They found that in dilute acids the gluten swells and "the discs puff up and take on an appearance somewhat resembling cotton balls, finally becoming transparent, soft and gelatinous." They furthermore found that the taking up and giving off of water was largely reversible and by neutralizing the acid after swelling of the disc had taken place, it would lose water and again become a firm coagulum.

In a later publication, the same investigators (1916) give results of further studies on the colloidal swelling of wheat gluten as related to baking strength of flour and conclude that "*strength is related to soluble acid and salt content of the flour. Flours containing acids and salts in such combinations as to favor water absorption will behave as "weak" flours, whereas those containing acids and salts in such combinations as inhibit water absorption will behave as "strong" flours when baked.*"

II - EXPERIMENTAL.

<u>The Problem</u>. In view of the interesting data and conclusions which Upson & Calvin (1915 & 1916) submit, it was thought worth while to repeat their work on the colloidal swelling of wheat gluten with a variety of flours of widely differing baking strength to determine what correlation, if any, exists between soluble salt, acid, and gluten content of the flour and the actual baking tests.

<u>The Material</u>. Five different flours were used. The first, a typical Washburn-Crosby patent grade milled from number one northern hard spring wheat from the 1916 crop. The second was a first clear grade milled from the 1915 crop. The other three samples were milled in the state of Oregon from typical soft wheats grown in that section, and are "straight grade" flours.

<u>The Method</u>. The method used in studying these flours was the same as that used by Hofmeister in his work on the swelling of gelatin and as mentioned above by Upson & Calvin. Briefly it consisted in first doughing 200 grams of flour by adding the required amount of distilled water. The dough was then permitted to stand for from thirty minutes to an hour under distilled water after which it was washed for fifteen minutes under a stream of distilled water. Almost all of the starch was washed out in this manner. The gluten was then submerged under distilled water until all the desired samples of gluten had been prepared.

It was interesting to note the difference in the character of the gluten prepared from the different samples. The patent flour from one northern grade of wheat, called "P", gave a rather firm coherent gluten, as did the first clear grade, "C".

The three western flours, designated "W_1", "W_2", and "W_3"respectively, all gave a more friable, sticky, and less coherent gluten which was in each case much more difficult to secure than was gluten from the other two flours, so greatly was it lacking in coherency. The gluten from each of these flours was then pressed out to a nearly uniform thickness of about 3 mm. between glass plates, and after draining for a few minutes, (this interval of time was kept as nearly constant as possible), cut into small discs by means of a large cork borer. These discs which were fairly uniform as to size, shape and weight, were weighed out to an accuracy of 5 mg., placed in acid solutions of varying compositions and concentrations and left for exactly fifty minutes. They were then removed, drained for about ten minutes on a perforated porcelain plate and reweighed. The change in weight was calculated to the change per gram of moist gluten. Preliminary experiments were undertaken in order to determine the maximum time during which glutens from all the flours could remain submerged in the various concentrations of the various acids and still retain their coherence sufficiently to make weighing possible. This time was found to be fifty minutes.

In order that the results with the different flours might be comparable, this time interval was kept exactly the same in all these experiments reported in the following tables. The glutens for any given set of experiments were prepared at the same time and placed in acids at the same temperature, Every possible precaution was taken to eliminate variations in experimental conditions and I believe that any appreciable difference between the recorded constants may be attributed to intrinsic differences in the various glutens themselves.

This method of measuring water absorption or "hydration capacity" is obviously somewhat crude when compared with the usual chemical procedure, but the errors are reduced to a minimum by taking the average of several different determinations as is shown in Tables I to IV inclusive.

The Experimental Data.

(1) The hydration capacity of the various glutens as determined in acid solutions. The Power of the various glutens to imbibe water was measured in eight concentrations of each of the following acids - hydrochloric, oxalic, lactic and acetic. The data determined from these experiments are shown in Tables I to IV inclusive and graphically in Figs. (I to IV).

(2) The antagonistic action of salts upon the imbibition of water by the various glutens in the presence of hydrochloric, oxalic, lactic and acetic acids. The hydration capacity of the various glutens was again measured as under (1) with the exception that .005M of KCl, KH_2PO_4, and $KHC_4H_4O_6$ respectively were added to the different series. Tables V to VIII inclusive show the effects of the added salts when present in the lactic acid solutions; Tables IX to XII, when present in the acetic acid solutions, Tables XIII to XVI, when present in the hydrochloric acid solutions and Tables XVII to XX, when present in the oxalic acid solutions.

(3) Flour analyses and Baking Tests. In Table XXI are shown the following data determined from either the analysis of the flour or from baking tests: ash on dry flour, soluble ash, percent soluble ash in total ash, gluten, wet and dry, ash on gluten, specific conductivity on flour extract, water added to make dough, volume of loaf, texture of loaf and expansimeter (Bailey 1916)test.

Table I - Lactic acid

Water absorbed in g. per g. moist gluten

Conc. of acid	P	P	P	C	C	C	W_1	W_1	W_1	W_2	W_2	W_2	Average P	Average C	Average W_1	Average W_2
None	0.01	-0.01	-0.01	-0.01	0.01	0.00	-0.01	0.00	0.01	0.02	0.00	-0.01	-0.03	0.01	0.00	-0.01
0.002N	0.64	0.57	0.69	0.65	0.57	0.74	0.12	0.11	0.12	0.30	0.15	0.23	0.64	0.65	0.12	0.23
0.005N	0.84	0.74	0.93	0.74	0.58	0.81	0.28	0.16	0.42	0.38	0.36	0.40	0.84	0.71	0.29	0.38
0.01 N	0.98	0.90	1.09	0.74	0.70	0.90	0.46	0.26	0.47	0.53	0.39	0.47	0.99	0.79	0.40	0.46
0.02 N	1.27	0.99	1.16	0.85	0.83	0.98	0.46	0.38	0.56	0.73	0.78	0.61	1.14	0.89	0.47	0.71
0.04 N	1.40	1.05	1.30	0.94	0.84	1.17	0.50	0.46	0.56	0.76	0.97	0.84	1.25	0.98	0.51	0.86
0.1 N	1.45	1.10	1.41	1.06	0.90	0.89	0.74	0.83	0.64	0.86	0.91	0.72	1.32	0.95	0.74	0.83
0.2 N	1.33	1.06	1.30	1.04	0.81	0.80	0.72	0.78	0.62	0.75	0.97	1.02	1.29	0.88	0.71	0.91
0.5 N	0.87	1.00	1.18	0.84	0.70	0.78	0.74	0.74	0.59	0.87	0.91	0.83	1.02	0.77	0.69	0.87
												Avg.	0.94	0.74	0.44	0.58

Table II - Acetic acid

Water absorbed in g. per g. moist gluten

Conc. of acid	P	P	P	C	C	C	W_1	W_1	W_1	W_2	W_2	W_2	Average P	Average C	Average W_1	Average W_2
None	0.01	0.00	0.00	0.03	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
0.002N	0.43	0.43	0.41	0.39	0.34	0.33	0.09	0.05	0.11	0.23	0.19	0.25	0.42	0.35	0.08	0.22
0.005	0.55	0.64	0.51	0.44	0.51	0.46	0.15	0.09	0.12	0.35	0.28	0.35	0.57	0.47	0.12	0.33
0.01	0.66	0.71	0.72	0.53	0.53	0.58	0.22	0.35	0.29	0.40	0.41	0.46	0.70	0.55	0.29	0.42
0.02	0.83	0.90	0.90	0.57	0.75	0.66	0.43	0.43	0.38	0.45	0.58	0.59	0.91	0.66	0.41	0.54
0.04	0.90	1.12	0.97	0.68	0.69	0.79	0.44	0.25	0.30	0.46	0.60	0.56	1.00	0.72	0.33	0.54
0.1	0.94	1.26	1.12	0.62	0.74	0.87	0.39	0.36	0.36	0.52	0.70	0.65	1.11	0.74	0.37	0.62
0.2	0.97	1.04	1.04	0.81	0.79	0.80	0.56	0.60	0.45	0.55	0.49	0.82	1.02	0.80	0.54	0.62
0.5	0.92	0.94	0.91	0.70	0.89	0.73	0.62	0.53	0.46	0.61	0.59	0.72	0.92	0.77	0.54	0.61
												Avg.	0.74	0.56	0.30	0.43

Table III - Hydrochloric acid

Water absorbed in g. per g. moist gluten.

Conc. of acid	P	P	P	C	C	C	W_1	W_1	W_1	W_2	W_2	W_2	Average			
													P	C	W_1	W_2
None	-0.04	-0.07	0.08	-0.08	-0.07	-0.05	-0.02	-0.06	0.00	0.01	0.02	0.00	-0.01	-0.07	-0.03	0.01
0.002N	0.57	0.57	0.44	0.62	0.55	0.56	0.28	0.27	0.27	0.36	0.33	0.34	0.53	0.58	0.27	0.34
0.005	0.69	0.77	0.69	0.69	0.73	0.64	0.44	0.44	0.45	0.51	0.49	0.42	0.72	0.69	0.44	0.47
0.01	0.74	0.76	0.87	0.62	0.84	0.67	0.45	0.49	0.53	0.55	0.58	0.52	0.79	0.71	0.49	0.55
0.02	0.72	0.82	0.81	0.71	0.73	0.58	0.46	0.56	0.51	0.53	0.52	0.47	0.79	0.67	0.51	0.51
0.04	0.44	0.52	0.50	0.65	0.53	0.57	0.56	0.49	0.55	0.45	0.43	0.41	0.49	0.58	0.53	0.43
0.1	0.15	0.11	0.19	0.22	0.15	0.18	0.12	0.18	0.20	0.21	0.18	0.24	0.15	0.18	0.17	0.21
0.2	-0.01	-0.03	-0.02	-0.01	-0.02	-0.04	0.03	0.06	0.06	0.05	0.05	0.04	-0.02	-0.03	0.05	0.05
0.5	-0.08	-0.09	-0.11	-0.11	-0.19	-0.12	-0.02	-0.02	-0.07	0.02	-0.04	-0.05	-0.09	-0.14	-0.04	-0.02
												Avg.	0.37	0.35	0.26	0.28

Table IV - Oxalic acid

Water absorbed in g. per g. moist gluten

onc. f acid	P	P	P	C	C	C	W_1	W_1	W_1	W_2	W_2	W_2	W_3	W_3	W_3	Average				
																P	C	W_1	W_2	W_3
one	-0.03	-0.05	-0.05	-0.07	0.05	-0.03	-0.01	0.00	-0.03	-0.02	-0.01	-0.01	0.06	-0.03	0.00	-0.04	-0.05	-0.01	-0.01	-0.03
.002N	0.34	0.32	0.23	0.27	0.35	0.26	0.31	0.12	0.25	0.26	0.27	0.29	0.27	0.25	0.21	0.29	0.29	0.23	0.27	0.24
.005	0.39	0.40	0.33	0.41	0.39	0.43	0.51	0.40	0.28	0.41	0.38	0.34	0.37	0.29	0.35	0.37	0.41	0.40	0.38	0.34
.01	0.45	0.42	0.40	0.47	0.44	0.45	0.41	0.36	0.34	0.42	0.47	0.42	0.46	0.47	0.42	0.42	0.45	0.37	0.44	0.45
.02	0.54	0.54	0.54	0.75	0.53	0.56	0.54	0.55	0.51	0.47	0.51	0.55	0.53	0.45	0.50	0.54	0.61	0.53	0.51	0.49
.04	0.59	0.58	0.57	0.60	0.68	0.60	0.73	0.49	0.55	0.51	0.56	0.52	0.58	0.53	0.65	0.58	0.66	0.59	0.53	0.59
.1	0.52	0.41	0.48	0.56	0.46	0.56	0.52	0.47	0.48	0.53	0.46	0.63	0.42	0.45	0.47	0.47	0.53	0.49	0.54	0.45
.2	0.29	0.26	0.26	0.29	0.31	0.29	0.35	0.27	0.42	0.32	0.30	0.41	0.29	0.28	0.36	0.27	0.30	0.35	0.34	0.31
.5	0.07	0.09	0.08	-0.01	0.08	0.00	0.14	0.10	0.15	0.10	0.14	0.15	0.10	0.09	0.12	0.08	-0.03	0.13	0.13	0.10
															Avg.	0.33	0.35	0.34	0.35	0.33

Table V

0.005M KCL Solution and Varying Concentrations of Lactic Acid.

Water absorbed in g. per g. moist gluten

Conc. of acid										Average			No Salt		
	P	P	P	C	C	C	W_3	W_3	W_3	P	C	W_3	P	C	W_3
None	-0.01	-0.03	-0.02	-0.28	-0.15	-0.30	-0.02	-0.07	-0.04	-0.02	-0.24	-0.04	0.00	0.04	0.00
0.002N	0.28	0.22	0.17	0.19	0.10	0.12	0.20	0.15	0.19	0.22	0.14	0.18	0.65	0.70	0.42
0.005	0.44	0.35	0.34	0.34	0.39	0.43	0.34	0.25	0.39	0.38	0.39	0.33	0.88	0.88	0.59
0.01	0.55	0.56	0.54	0.52	0.47	0.66	0.35	0.40	0.43	0.55	0.55	0.39	0.97	0.94	0.67
0.02	0.62	0.63	0.74	0.60	0.64	0.70	0.61	0.51	0.51	0.66	0.65	0.54	1.15	0.86	0.86
0.04	0.78	0.81	0.78	0.68	0.76	0.76	0.61	0.56	0.65	0.79	0.73	0.61	1.32	1.17	1.01
0.1	0.88	0.96	0.97	0.93	0.91	0.87	0.67	0.67	0.92	0.94	0.90	0.75	1.19	1.07	0.99
0.2	1.16	1.00	0.99	0.80	0.87	0.88	0.79	0.76	1.01	1.05	0.85	0.85	1.11	1.31	0.90
0.5	0.96	0.89	1.03	0.71	0.71	0.93	0.80	0.90	0.79	0.96	0.78	0.83	1.04	0.85	0.84

Table VI

0.005M KH_2PO_4 Solution and Varying Concentrations of Lactic Acid.

Water absorbed in g. per g. moist gluten.

Conc. of acid										Average			No Salt		
	P	P	P	C	C	C	W_3	W_3	W_3	P	C	W_3	P	C	W_3
None	-0.13	-0.10	-0.02	-0.10	-0.12	-0.18	-0.05	-0.04	-0.07	-0.08	-0.13	-0.05	0.01	0.02	-0.01
0.002N	0.21	0.26	0.19	0.25	0.20	0.21	0.21	0.19	0.24	0.22	0.22	0.21	0.58	0.57	0.35
0.005N	0.42	0.37	0.35	0.35	0.26	0.33	0.35	0.28	0.32	0.38	0.31	0.32	0.73	0.66	0.52
0.01	0.49	0.58	0.43	0.76	0.56	0.68	0.51	0.43	0.67	0.50	0.67	0.54	0.81	0.70	0.82
0.02	0.66	0.60	0.63	0.92	0.77	0.59	0.58	0.60	0.67	0.63	0.76	0.62	1.07	0.73	0.94
0.04	0.73	0.74	0.85	0.93	0.67	0.77	0.63	0.75	0.96	0.77	0.79	0.78	1.10	0.96	0.99
0.1	0.82	0.73	0.94	0.86	0.93	1.00	0.80	0.82	1.03	0.83	0.93	0.88	1.14	0.94	1.06
0.2	0.89	0.83	0.98	1.08	0.85	0.99	0.77	0.83	0.89	0.90	0.97	0.83	0.95	0.91	0.96
0.5	0.82	0.98	0.99	0.88	0.93	0.97	0.74	0.72	0.98	0.93	0.93	0.81	1.01	0.77	0.96

Table VII

0.005M monobasic potassium tartrate and Varying Concentrations of Lactic Acid

Water absorbed in g. per g. moist gluten

Conc. of acid										Average			No Salt		
	P	P	P	C	C	C	W_3	W_3	W_3	P	C	W_3	P	C	W
None	0.01	0.08	0.04	0.05	0.06	0.05	0.06	0.05	0.09	0.04	0.05	0.07	0.01	0.01	0.02
0.002N	0.04	0.13	0.13	0.19	0.14	0.12	0.16	0.12	0.17	0.10	0.10	0.15	0.62	0.67	0.47
0.005	0.28	0.35	0.30	0.40	0.32	0.34	0.26	0.24	0.23	0.31	0.35	0.24	0.78	0.75	0.60
0.01	0.43	0.44	0.36	0.65	0.46	0.51	0.35	0.36	0.36	0.41	0.54	0.36	0.83	0.95	0.77
0.02	0.70	0.79	0.70	0.86	0.59	0.76	0.46	0.49	0.49	0.73	0.74	0.48	0.98	1.20	0.88
0.04	0.85	0.77	0.69	0.76	0.73	0.93	0.65	0.60	0.71	0.77	0.81	0.65	1.17	1.09	1.15
0.1	0.88	0.98	0.90	0.85	0.80	0.92	0.72	0.78	0.71	0.92	0.85	0.74	1.13	1.05	1.10
0.2	1.02	0.92	0.92	1.25	1.04	1.03	0.74	0.74	0.96	0.95	1.11	0.81	1.06	1.10	1.03
0.5	0.89	1.01	1.14	0.97	0.81	0.96	0.62	0.93	0.73	1.01	0.91	0.76	0.94	0.96	0.94

Table VIII - Lactic acid and various salts.

Conc. of acid	Water Absorbed in g. per g. moist gluten Avg. of 3 "No Salt" checks			Decrease in water absorption in g. per g. moist gluten due to presence of various salts								
				KCL			KH_2PO_4			KHC_4H_4 06		
	P	C	W_3	P	C	W_3	P	C	W_3	P	C	W_3
None	0.01	0.02	0.00	0.03	0.26	0.04	0.09	0.15	0.05	-0.03	-0.03	-0.07
0.002N	0.62	0.65	0.41	0.40	0.51	0.23	0.40	0.43	0.20	0.52	0.50	0.26
0.005N	0.80	0.76	0.57	0.42	0.37	0.24	0.42	0.45	0.25	0.49	0.41	0.33
0.01	0.87	0.86	0.75	0.32	0.31	0.36	0.37	0.19	0.21	0.46	0.32	0.39
0.02	1.07	0.93	0.89	0.41	0.28	0.35	0.44	0.17	0.27	0.34	0.19	0.41
0.04	1.20	1.07	1.05	0.41	0.34	0.44	0.43	0.28	0.27	0.43	0.26	0.40
0.1	1.15	1.02	1.05	0.21	0.12	1.30	0.32	0.09	0.17	0.23	0.17	0.31
0.2	1.04	1.11	0.96	-0.01	0.26	0.11	0.14	0.13	0.13	0.09	0.00	0.15
0.5	1.00	0.86	0.91	0.04	0.08	0.08	0.07	-0.07	0.10	-0.01	-0.05	0.15
Avg.-	0.86	0.81	0.73	0.25	0.28	0.24	0.30	0.20	0.18	0.28	0.19	0.26

Table IX

0.005M KCL Solution and Varying Concentrations of Acetic Acid.

Water absorbed in g. per g. moist gluten.

Conc. of acid	P	P	P	C	C	C	W_3	W_3	W_3	Average			No Salt		
										P	C	W_3	P	C	W_3
None	-0.14	-0.12	-0.05	-0.16	-0.17	-0.10	-0.07	-0.07	-0.05	-0.10	-0.14	-0.06	0.01	0.04	0.02
0.002N	0.07	0.07	0.06	0.06	0.06	0.06	0.11	0.13	0.10	0.07	0.06	0.11	0.57	0.58	0.39
0.005	0.19	0.20	0.21	0.28	0.19	0.15	0.27	0.24	0.21	0.20	0.21	0.24	0.81	0.90	0.55
0.01	0.31	0.32	0.27	0.43	0.42	0.42	0.33	0.28	0.30	0.30	0.42	0.30	0.89	0.92	0.61
0.02	0.41	0.39	0.43	0.60	0.78	0.64	0.37	0.38	0.36	0.42	0.67	0.37	0.98	1.13	0.68
0.04	0.51	0.51	0.50	0.64	0.82	0.68	0.46	0.50	0.50	0.51	0.71	0.49	1.05	0.94	0.76
0.1	0.52	0.56	0.65	0.79	0.81	0.69	0.51	0.55	0.60	0.58	0.76	0.55	1.17	1.24	0.94
0.2	0.57	0.67	0.63	0.73	0.78	0.73	0.62	0.64	0.66	0.62	0.75	0.64	1.27	1.21	0.86
0.5	0.70	0.77	0.69	0.74	0.66	0.77	0.63	0.56	0.72	0.72	0.72	0.64	1.14	1.17	0.94

Table X

0.005M KH_2PO_4 Solution and Varying Concentrations of Acetic Acid.

Water absorbed in g. per g. moist gluten.

Conc. of acid	P	P	P	C	C	C	W_3	W_3	W_3	Average			No Salt		
										P	C	W_3	P	C	W_3
None	-0.03	-0.01	-0.08	-0.05	-0.01	-0.06	-0.02	-0.01	-0.09	-0.04	-0.04	-0.04	0.05	0.04	0.05
0.002N	0.23	0.19	0.13	0.26	0.20	0.16	0.16	0.21	0.16	0.18	0.21	0.18	0.61	0.51	0.40
0.005	0.31	0.30	0.23	0.35	0.30	0.23	0.28	0.33	0.35	0.28	0.29	0.32	0.66	0.78	0.44
0.01	0.39	0.45	0.32	0.48	0.33	0.31	0.30	0.35	0.23	0.39	0.37	0.29	0.79	0.80	0.52
0.02	0.46	0.49	0.51	0.57	0.52	0.36	0.42	0.42	0.30	0.41	0.48	0.38	0.82	0.88	0.54
0.04	0.57	0.60	0.46	0.59	0.68	0.42	0.43	0.53	0.39	0.54	0.56	0.45	1.11	0.90	0.73
0.1	0.58	0.66	0.75	0.55	0.66	0.70	0.57	0.61	0.48	0.66	0.64	0.55	1.05	1.18	0.98
0.2	0.81	0.67	0.82	0.68	0.66	0.71	0.64	0.63	0.53	0.77	0.68	0.60	1.06	0.98	1.13
0.5	0.73	0.76	0.81	0.74	0.70	0.63	0.70	0.61	0.63	0.77	0.69	0.65	1.03	0.95	0.94

Table XI

0.005M Monobasic potassium tartrate and varying concentrations of Acetic Acid.

Water absorbed in g. per g. moist gluten.

Conc. of acid	P	P	P	C	C	C	W_3	W_3	W_3	Average P	Average C	Average W_3	No Salt P	No Salt C	No Salt W_3
None	0.01	0.03	0.01	-0.09	-0.05	-0.07	0.09	0.10	0.09	0.02	-0.08	0.09	-0.01	-0.02	0.02
0.002N	0.05	0.06	0.04	-0.02	0.09	0.01	0.09	0.12	0.16	0.05	0.03	0.12	0.44	0.59	0.37
0.005	0.14	0.12	0.13	0.14	0.14	0.07	0.15	0.19	0.18	0.13	0.12	0.17	0.72	0.80	0.45
0.01	0.27	0.23	0.21	0.33	0.37	0.22	0.19	0.25	0.27	0.24	0.31	0.24	0.80	0.80	0.55
0.02	0.28	0.35	0.26	0.67	0.40	0.45	0.28	0.29	0.32	0.30	0.51	0.30	1.08	1.06	0.66
0.04	0.50	0.59	0.38	0.70	0.45	0.54	0.33	0.38	0.36	0.49	0.56	0.36	0.99	1.34	0.69
0.1	0.67	0.68	0.59	0.69	0.65	0.53	0.43	0.50	0.45	0.65	0.62	0.46	0.97	1.16	1.03
0.2	0.57	0.60	0.70	0.85	0.62	0.77	0.45	0.53	0.62	0.62	0.75	0.53	0.96	1.09	0.65
0.5	0.69	0.70	0.82	0.70	0.73	0.77	0.56	0.61	0.63	0.74	0.80	0.60	1.09	0.95	0.89

Table XII

Water absorbed in
g. per g. moist gluten
Avg. of 3 "No Salt" checks

Decrease in water absorption in g. per g. moist gluten
due to presence of various salts.

Conc. of acid	P	C	W_3	KCL P	KCL C	KCL W_3	KH_2PO_4 P	KH_2PO_4 C	KH_2PO_4 W_3	$KHC_4H_4O_6$ P	$KHC_4H_4O_6$ C	$KHC_4H_4O_6$ W_3
None	0.02	0.02	0.03	0.12	0.16	0.09	0.06	0.05	0.07	0.00	-0.10	-0.06
0.002	0.54	0.56	0.39	0.37	0.50	0.29	0.36	0.35	0.21	0.49	0.53	0.27
0.005	0.73	0.83	0.48	0.53	0.52	0.24	0.45	0.54	0.16	0.60	0.71	0.31
0.01	0.83	0.83	0.56	0.53	0.41	0.26	0.44	0.46	0.27	0.59	0.52	0.32
0.02	0.96	1.02	0.63	0.54	0.35	0.26	0.47	0.54	0.25	0.66	0.51	0.33
0.04	1.05	1.03	0.69	0.54	0.32	0.20	0.51	0.47	0.24	0.56	0.47	0.33
0.1	0.96	1.19	0.98	0.38	0.43	0.43	0.30	0.55	0.43	0.31	0.57	0.52
0.2	1.09	1.09	0.95	0.47	0.34	0.31	0.32	0.41	0.35	0.47	0.34	0.42
0.5	1.08	1.02	0.92	0.36	0.30	0.28	0.31	0.33	0.27	0.34	0.22	0.32
Avg.	0.56	0.84	0.63	0.43	0.38	0.26	0.36	0.41	0.25	0.45	0.42	0.31

Table XIII

0.005M KCL solution and Varying Concentrations of Hydrochloric Acid.

Water absorbed in g. per g. moist gluten.

									Average			No Salt		
Conc. of acid	P	P	P	C	C	C	W_3	W_3	W_3	P	C	W_3	P	C	W_3
None	-0.11	-0.07	-0.08	-0.25	-0.07	-0.08	-0.03	-0.02	-0.04	-0.09	-0.13	-0.03	-0.03	-0.07	0.01
0.002N	0.40	0.26	0.26	0.22	0.19	0.18	0.25	0.26	0.22	0.31	0.20	0.24	0.51	0.71	0.48
0.005	0.43	0.42	0.42	0.40	0.36	0.40	0.39	0.51	0.40	0.42	0.39	0.43	0.77	0.74	0.71
0.01	0.81	0.55	0.64	0.51	0.54	0.48	0.59	0.53	0.52	0.67	0.51	0.55	0.82	0.84	0.88
0.02	0.64	0.70	0.68	0.49	0.52	0.63	0.63	0.64	0.73	0.68	0.55	0.67	0.75	0.65	0.83
0.04	0.44	0.52	0.50	0.34	0.38	0.55	0.48	0.58	0.45	0.49	0.42	0.50	0.51	0.49	0.70
0.1	0.10	0.18	0.22	0.12	0.08	0.17	0.22	0.23	0.19	0.17	0.12	0.21	0.17	0.12	0.27
0.2	-0.05	0.01	0.01	-0.15	-0.09	-0.01	0.04	0.02	0.05	-0.01	-0.08	0.04	-0.02	-0.12	0.04
0.5	-0.16	-0.12	-0.10	-0.29	-0.19	-0.17	-0.03	-0.05	-0.05	-0.13	-0.22	-0.04	-0.13	-0.24	-0.01

Table XIV

0.005M KH_2PO_4 Solution and Varying Concentrations of Hydrochloric Acid.

Water absorbed in g. per g. moist gluten.

									Average			No Salt		
Conc. of acid	P	P	P	C	C	C	W_3	W_3	W_3	P	C	W_3	P	C	W_3
None	-0.09	-0.09	-0.08	-0.05	-0.05	-0.10	-0.03	-0.03	-0.03	-0.09	-0.07	-0.03	-0.05	-0.02	-0.01
0.002N	0.37	0.33	0.34	0.42	0.26	0.32	0.38	0.33	0.27	0.35	0.33	0.33	0.67	0.75	0.42
0.005	0.54	0.61	0.58	0.47	0.50	0.51	0.52	0.43	0.51	0.58	0.49	0.49	0.88	0.65	0.60
0.01	0.61	0.72	0.63	0.59	0.61	0.63	0.53	0.59	0.70	0.66	0.61	0.62	0.84	0.72	0.80
0.02	0.66	0.67	0.69	0.66	0.59	0.63	0.60	0.67	0.61	0.67	0.63	0.63	0.69	0.81	0.65
0.04	0.58	0.54	0.59	0.48	0.53	0.50	0.46	0.58	0.65	0.57	0.50	0.56	0.50	0.58	0.53
0.1	0.20	0.19	0.19	0.10	0.11	0.21	0.29	0.22	0.20	0.19	0.14	0.22	0.22	0.20	0.28
0.2	0.01	-0.02	-0.03	-0.09	-0.13	-0.05	0.06	0.04	0.05	-0.01	-0.09	0.05	-0.07	-0.11	0.08
0.5	-0.19	-0.17	-0.17	-0.28	-0.27	-0.19	-0.05	-0.10	-0.05	-0.18	-0.25	-0.07	-0.15	-0.24	-0.03

Table XV

0.005M monobasic potassium tartrate and Varying Concentrations of Hydrochloric Acid.

Water absorbed in g. per g. moist gluten.

Conc. of acid	P	P	P	C	C	C	W_3	W_3	W_3	Average P	Average C	Average W_3	No Salt P	No Salt C	No Salt W_3
None	0.05	0.03	0.05	0.06	0.08	0.05	0.11	0.05	0.10	0.04	0.07	0.09	-0.02	-0.10	-0.02
0.002N	0.15	0.18	0.14	0.20	0.17	0.16	0.16	0.16	0.31	0.15	0.18	0.21	0.61	0.36	0.47
0.005	0.32	0.32	0.27	0.36	0.42	0.25	0.38	0.32	0.34	0.30	0.34	0.35	0.81	0.52	0.62
0.01	0.66	0.64	0.43	0.59	0.64	0.45	0.52	0.52	0.54	0.58	0.55	0.53	0.97	0.79	0.71
0.02	0.62	0.50	0.64	0.50	0.70	0.54	0.64	0.54	0.64	0.59	0.58	0.61	0.64	0.84	0.56
0.04	0.42	0.40	0.38	0.58	0.49	0.45	0.49	0.42	0.66	0.47	0.51	0.52	0.57	0.52	0.60
0.1	0.14	0.15	0.18	0.18	0.20	0.18	0.22	0.22	0.29	0.16	0.19	0.24	0.18	0.23	0.25
0.2	-0.02	0.05	0.04	0.02	0.03	0.08	0.05	0.04	0.02	0.02	0.04	0.04	0.04	0.03	0.07
0.5	-0.13	-0.04	0.01	-0.09	-0.09	-0.05	-0.02	-0.01	-0.07	-0.05	-0.08	-0.03	-0.11	-0.08	-0.08

Table XVI - Hydrochloric Acid and Various Salts

Water absorbed in
g. per g. moist gluten
Avg. of 3 "No Salt" checks

Decrease in water absorption in g. per g. moist gluten
due to presence ofvarious salts.

Conc. of acid	P	C	W_3	KCL P	KCL C	KCL W_3	KH_2PO_4 P	KH_2PO_4 C	KH_2PO_4 W_3	$KHC_4H_4O_6$ P	$KHC_4H_4O_6$ C	$KHC_4H_4O_6$ W_3
None	-0.03	-0.06	-0.01	0.06	0.07	0.02	0.06	0.01	0.02	-0.07	-0.13	-0.10
0.002N	0.60	0.61	0.46	0.29	0.41	0.22	0.25	0.28	0.13	0.44	0.43	0.25
0.005	0.82	0.64	0.64	0.40	0.25	0.21	0.24	0.15	0.15	0.52	0.30	0.29
0.01	0.88	0.78	0.80	0.21	0.27	0.25	0.22	0.17	0.18	0.30	0.22	0.29
0.02	0.69	0.77	0.68	0.01	0.22	0.01	0.02	0.14	0.15	0.10	0.19	0.07
0.04	0.53	0.53	0.62	0.04	0.11	0.12	-0.04	0.03	0.06	0.05	0.02	0.10
0.1	0.19	0.18	0.27	0.02	0.06	0.05	0.00	0.04	0.05	0.03	-0.01	0.03
0.2	-0.02	-0.07	0.05	-0.01	0.01	0.02	-0.01	0.02	0.01	-0.04	-0.11	0.02
0.5	-0.13	-0.19	-0.04	0.00	0.03	0.00	0.03	0.06	0.03	-0.08	-0.11	-0.01
Avg.	0.39	0.35	0.38	0.11	0.16	0.10	0.09	0.10	0.09	0.14	0.09	0.10

Table XVII

0.005M KCL Solution and Varying Concentrations of Oxalic Acid.

Wt. water absorbed in g. per g. moist gluten.

Conc.										Average			No Salt	
of acid	P	P	P	C	C	C	W_3	W_3	W_3	P	C	W_3	P	C	W_3
None	-0.14	-0.10	-0.10	-0.07	-0.08	-0.18	-0.04	-0.04	0.05	-0.11	-0.11	-0.04	-0.02	-0.01	0.06
0.002N	0.10	0.15	0.10	0.25	0.13	0.13	0.19	0.14	0.15	0.12	0.17	0.16	0.31	0.33	0.25
0.005	0.21	0.24	0.21	0.31	0.26	0.15	0.28	0.25	0.18	0.22	0.24	0.24	0.41	0.56	0.33
0.01	0.41	0.36	0.32	0.44	0.38	0.31	0.44	0.37	0.34	0.36	0.38	0.38	0.57	0.54	0.44
0.02	0.59	0.47	0.44	0.52	0.55	0.43	0.51	0.46	0.44	0.47	0.50	0.47	0.76	0.54	0.56
0.04	0.59	0.52	0.49	0.69	0.66	0.55	0.49	0.43	0.51	0.53	0.63	0.48	0.63	0.68	0.57
0.1	0.41	0.43	0.39	0.34	0.48	0.46	0.43	0.40	0.49	0.41	0.49	0.44	0.52	0.61	0.58
0.2	0.31	0.25	0.21	0.25	0.19	0.21	0.27	0.23	0.23	0.25	0.22	0.24	0.32	0.48	0.28
0.5	0.05.	0.06	0.05	0.12	0.03	0.01	0.11	0.10	0.12	0.06	0.05	0.11	0.10	0.14	0.12

Table XVIII

0.005M KH_2PO_4 Solution and Varying Concentrations of Oxalis Acid.

Wt. water absorbed in g. per g. moist gluten.

Conc.										Average			No Salt		
of acid	P	P	P	C	C	C	W_3	W_3	W_3	P	C	W_3	P	C	W_3
None	-0.03	-0.06	-0.03	-0.13	-0.08	0.05	-0.06	-0.09	-0.09	-0.04	-0.10	-0.08	0.01	0.00	0.01
0.002N	0.24	0.20	0.19	0.16	0.20	0.11	0.21	0.17	0.22	0.21	0.16	0.20	0.40	0.32	0.25
0.005	0.40	0.39	0.34	0.32	0.32	0.33	0.31	0.30	0.33	0.38	0.32	0.31	0.58	0.47	0.34
0.01	0.59	0.48	0.47	0.49	0.33	0.39	0.36	0.45	0.46	0.51	0.40	0.42	0.57	0.69	0.56
0.02	0.77	0.56	0.59	0.52	0.56	0.54	0.60	0.48	0.56	0.64	0.54	0.55	0.64	0.74	0.66
0.04	0.62	0.73	0.75	0.82	0.63	0.66	0.59	0.62	0.71	0.70	0.70	0.64	0.66	0.69	0.74
0.1	0.58	0.58	0.66	0.72	0.63	0.55	0.59	0.56	0.58	0.61	0.63	0.58	0.61	0.72	0.75
0.2	0.36	0.37	0.38	0.44	0.33	0.29	0.35	0.30	0.39	0.37	0.35	0.35	0.40	0.55	0.50
0.5	0.11	0.14	0.12	0.08	0.09	0.11	0.11	0.13	0.14	0.12	0.05	0.13	0.14	0.16	0.20

Table XIX

0.005M Monobasic Potassium tartrate and Varying Concentrations of Oxalic Acid.

Water absorbed in g. per g. moist gluten.

Conc. of acid										Average			No Salt		
	P	P	P	C	C	C	W_3	W_3	W_3	P	C	W_3	P	C	W_3
None	0.05	0.02	0.02	-0.01	-0.04	0.00	0.06	0.07	0.10	0.03	-0.02	0.08	0.00	-0.02	-0.02
0.002N	0.08	0.07	0.10	0.06	0.04	0.02	0.11	0.10	0.13	0.08	0.04	0.11	0.39	0.22	0.34
0.005	0.12	0.15	0.16	0.18	0.10	0.14	0.18	0.19	0.18	0.14	0.14	0.18	0.45	0.45	0.37
0.01	0.27	0.30	0.36	0.30	0.24	0.27	0.24	0.25	0.23	0.31	0.27	0.24	0.63	0.63	0.50
0.02	0.37	0.46	0.49	0.52	0.49	0.47	0.41	0.41	0.38	0.44	0.49	0.40	0.72	0.57	0.68
0.04	0.50	0.49	0.60	0.86	0.77	0.49	0.50	0.52	0.50	0.53	0.71	0.51	0.55	0.67	0.66
0.1	0.57	0.50	0.53	0.63	0.65	0.56	0.44	0.48	0.55	0.53	0.61	0.49	0.52	0.67	0.60
0.2	0.33	0.31	0.31	0.50	0.49	0.44	0.31	0.32	0.33	0.32	0.48	0.32	0.40	0.50	0.31
0.5	0.10	0.10	0.13	0.20	0.11	0.19	0.15	0.14	0.16	0.11	0.17	0.15	0.16	0.22	0.14

Table XX - Oxalic Acids and Various Salts.

Decrease in water absorption in g. per g. moist gluten
due to presence of various salts.

Conc. of acid	Water absorbed in g. per g. moist gluten Avg. of 3 "No Salt" checks			KCL			KH_2PO_4			$KHC_4H_4O_6$		
	P	C	W_3	P	C	W_3	P	C	W_3	P	C	W_3
None	0.00	-0.01	0.02	0.11	0.10	0.06	0.04	0.09	0.10	-0.03	0.01	-0.06
0.002N	0.37	0.29	0.28	0.25	0.12	0.12	0.16	0.13	0.08	0.29	0.25	0.19
0.005	0.48	0.49	0.35	0.26	0.25	0.12	0.10	0.17	0.04	0.34	0.35	0.17
0.01	0.59	0.62	0.50	0.23	0.24	0.12	0.08	0.22	0.08	0.28	0.35	0.26
0.02	0.77	0.62	0.63	0.30	0.12	0.16	0.13	0.08	0.08	0.33	0.13	0.23
0.04	0.65	0.68	0.66	0.12	0.05	0.18	-0.05	-0.02	0.02	0.12	-0.03	0.15
0.1	0.55	0.67	0.64	0.14	0.18	0.20	-0.06	0.04	0.06	0.02	0.06	0.15
0.2	0.37	0.51	0.36	0.11	0.29	0.12	0.00	0.16	0.01	0.05	0.03	0.04
0.5	0.13	0.17	0.15	0.07	0.12	0.04	0.04	0.08	0.02	0.02	0.00	0.00
Avg.	0.43	0.45	0.40	0.17	0.16	0.12	0.05	0.11	0.55	0.16	0.13	0.13

Table XXI - Baking Tests.

Sample No.	Ash on dry flour %	Soluble ash %	Percent soluble is of total ash	Gluten wet %	Gluten dry %	Ash on dry gluten %	pecific onductivity of flour ext.	Additional water used cc.	Vol. of loaf cc.	Texture	Expansimeter test cc.
P	.46	.27	59.32	30.23	10.02	.31	.001080	60	1440	100	870
C	.56	.33	58.78	32.39	10.57	.32	.001218	52	1405	95	775
W_1	.61	.40	64.22	24.11	7.68	.55	.001461	42	1345	97	650
W_2	.62	.37	55.40	17.56	6.66	.42	.001289	47	1220	96	620
W_3	.49	.30	61.00	25.45	7.28	.39	.001035	49	1320	95	620

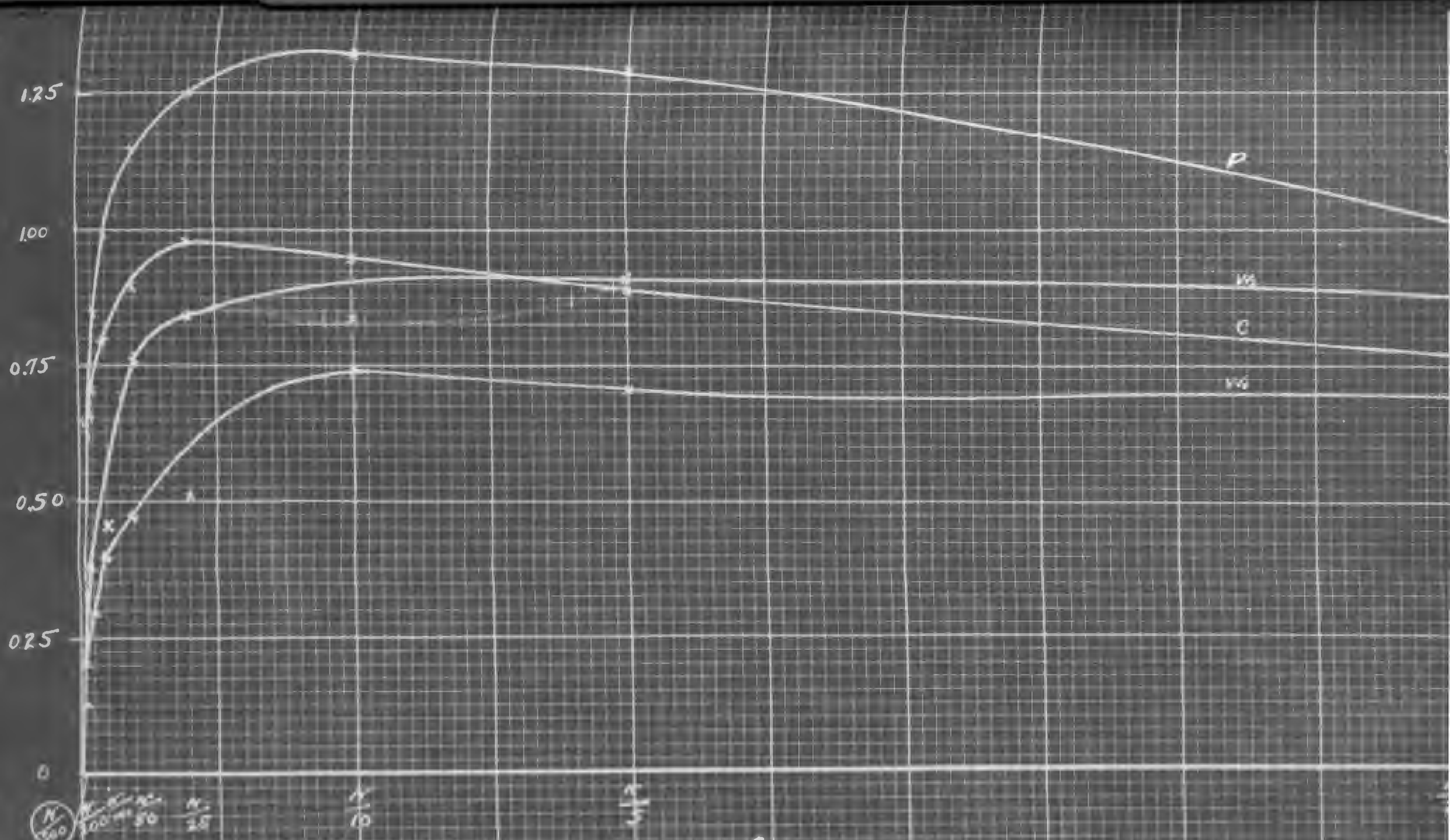

Fig I. Lactic Acid

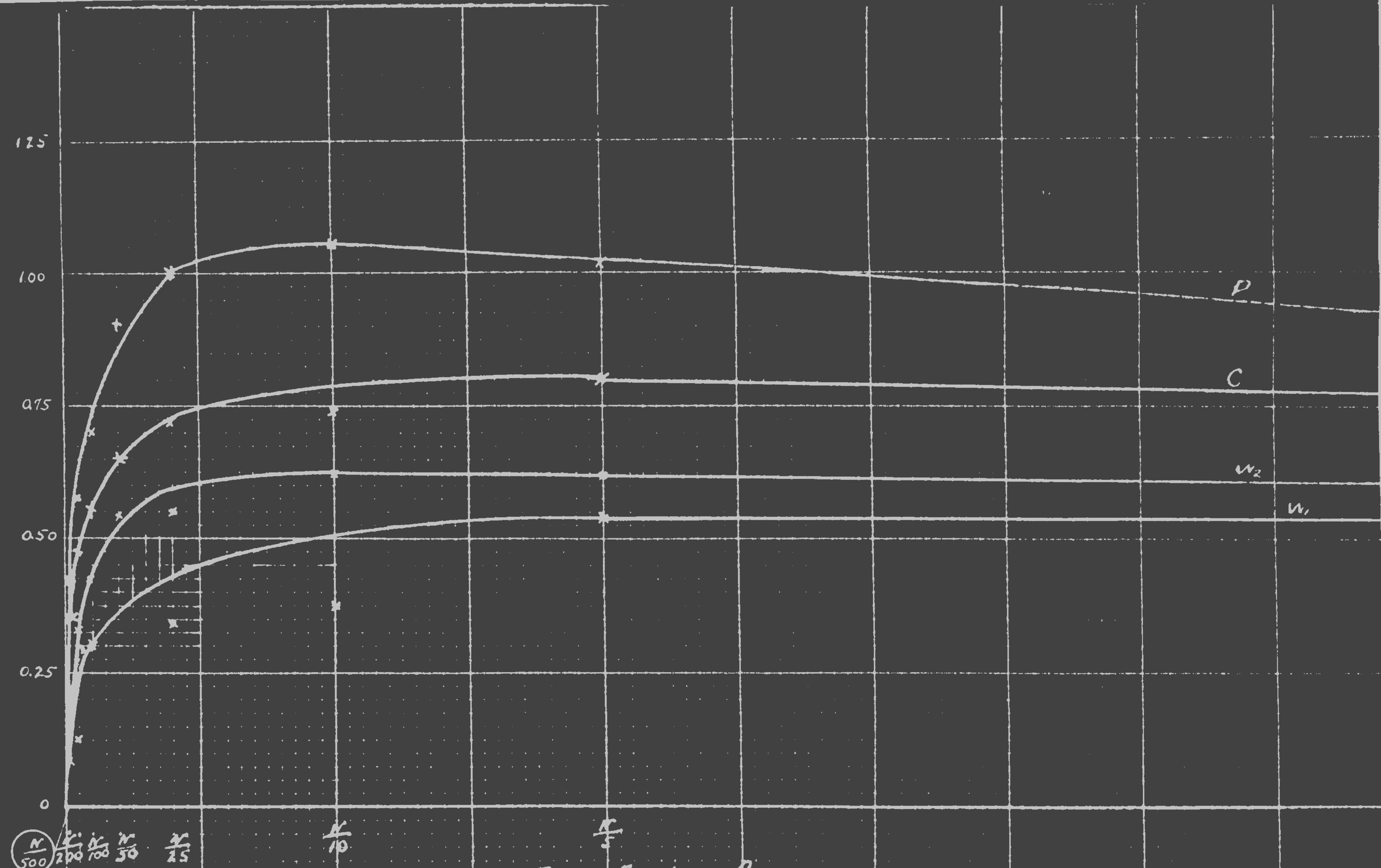

Fig II Acetic Acid

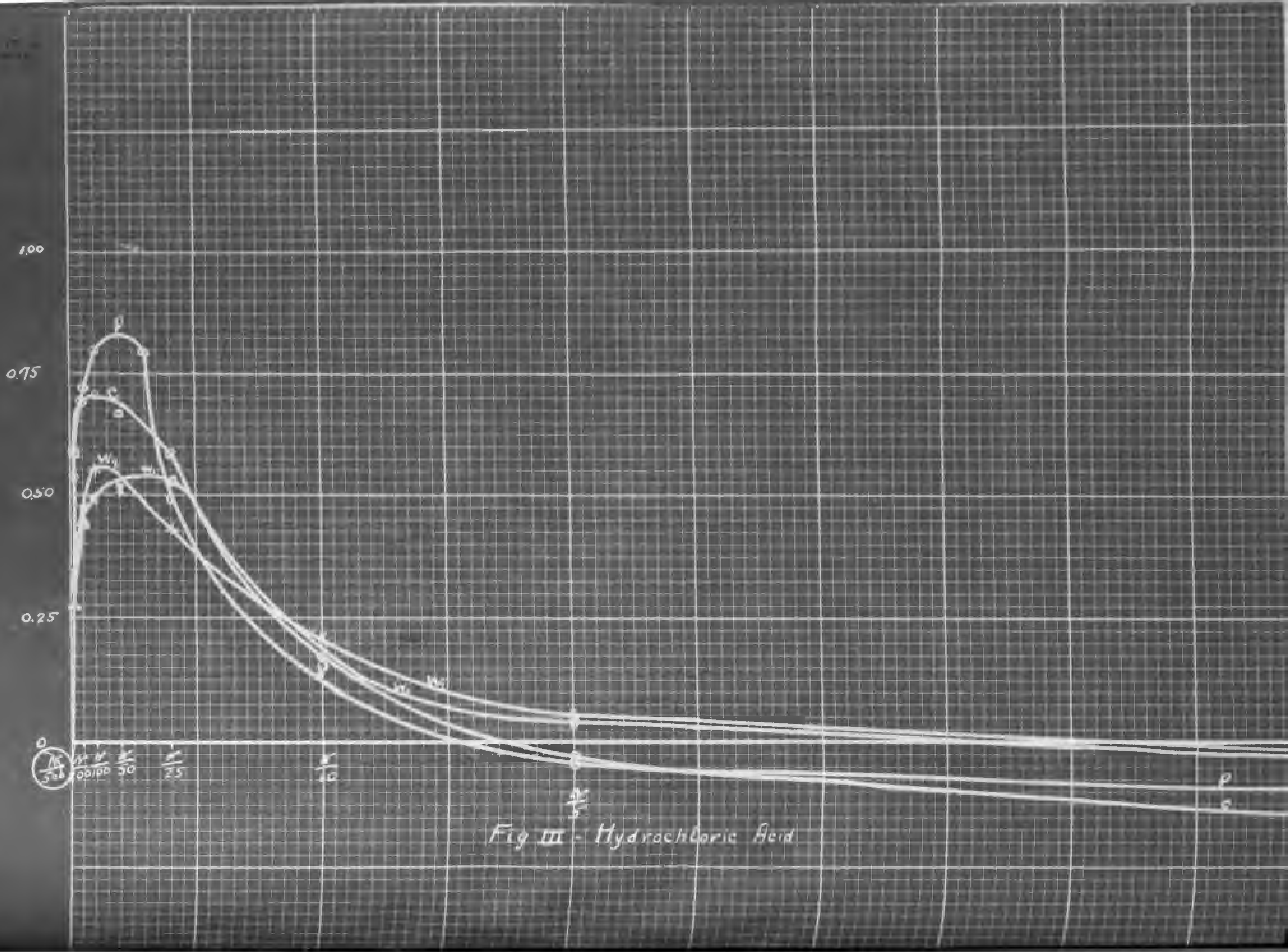

Fig III - Hydrochloric Acid

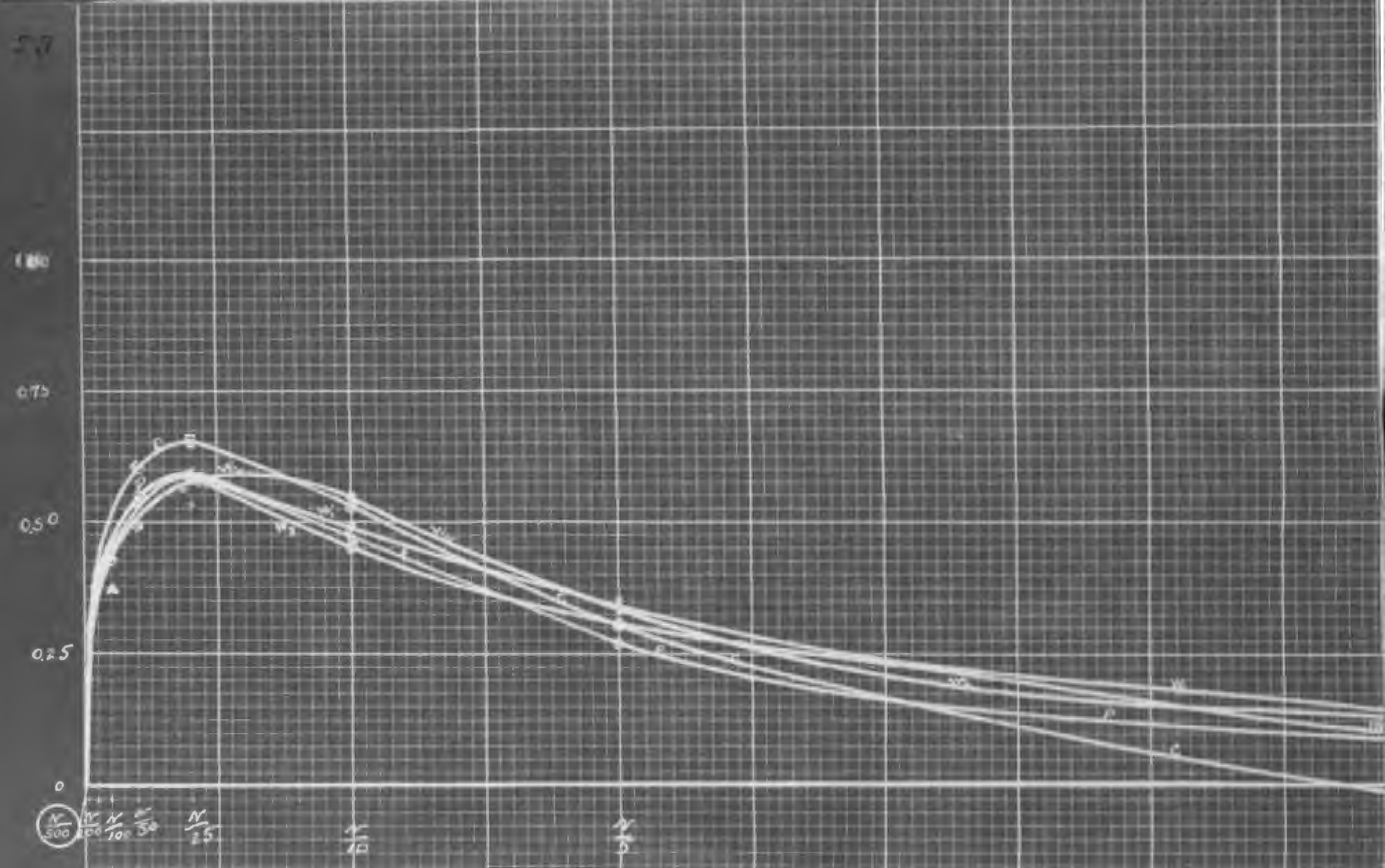

Fig IV Oxalic Acid

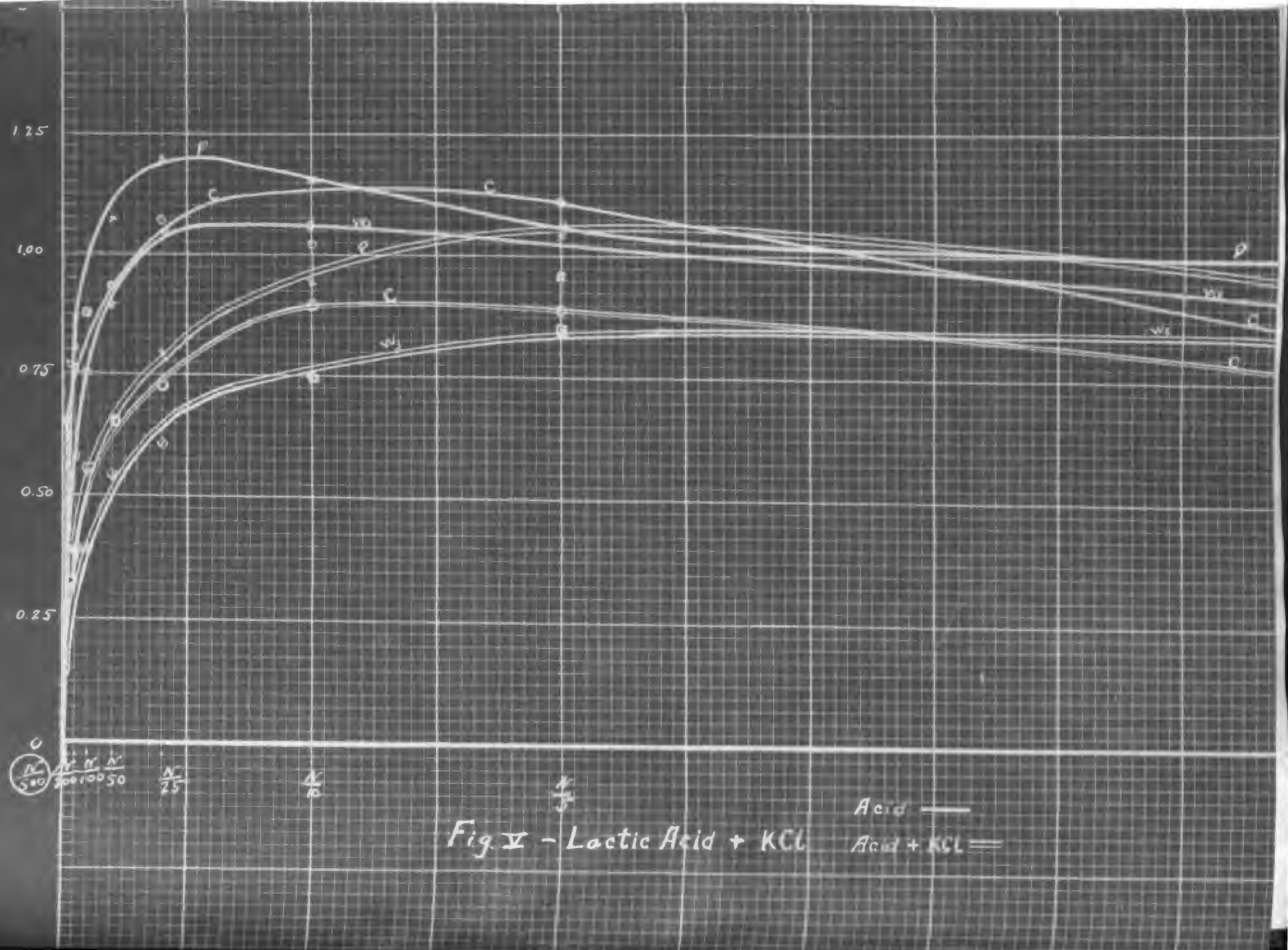

Fig. V – Lactic Acid + KCl

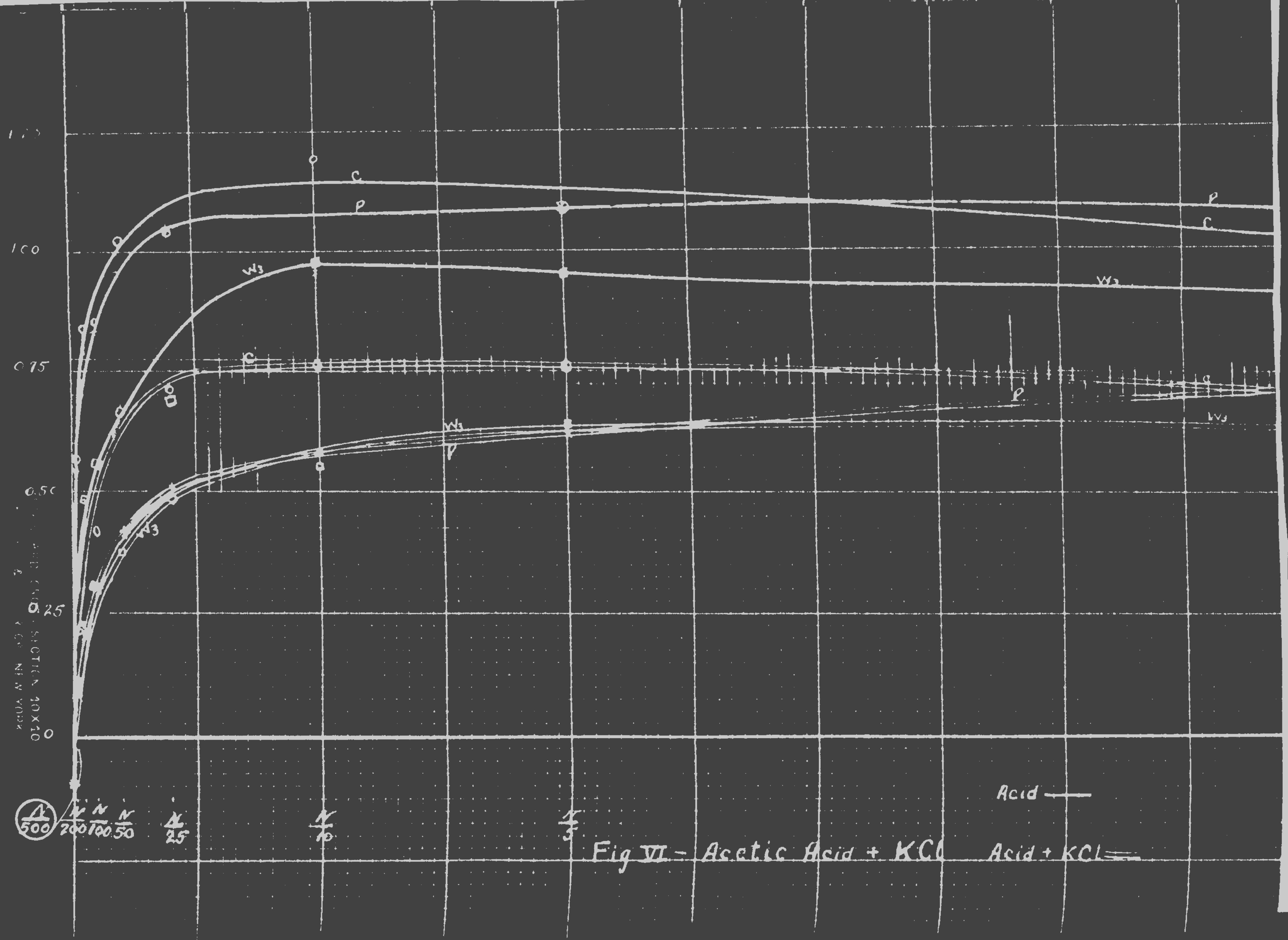

Fig VI - Acetic Acid + KCl

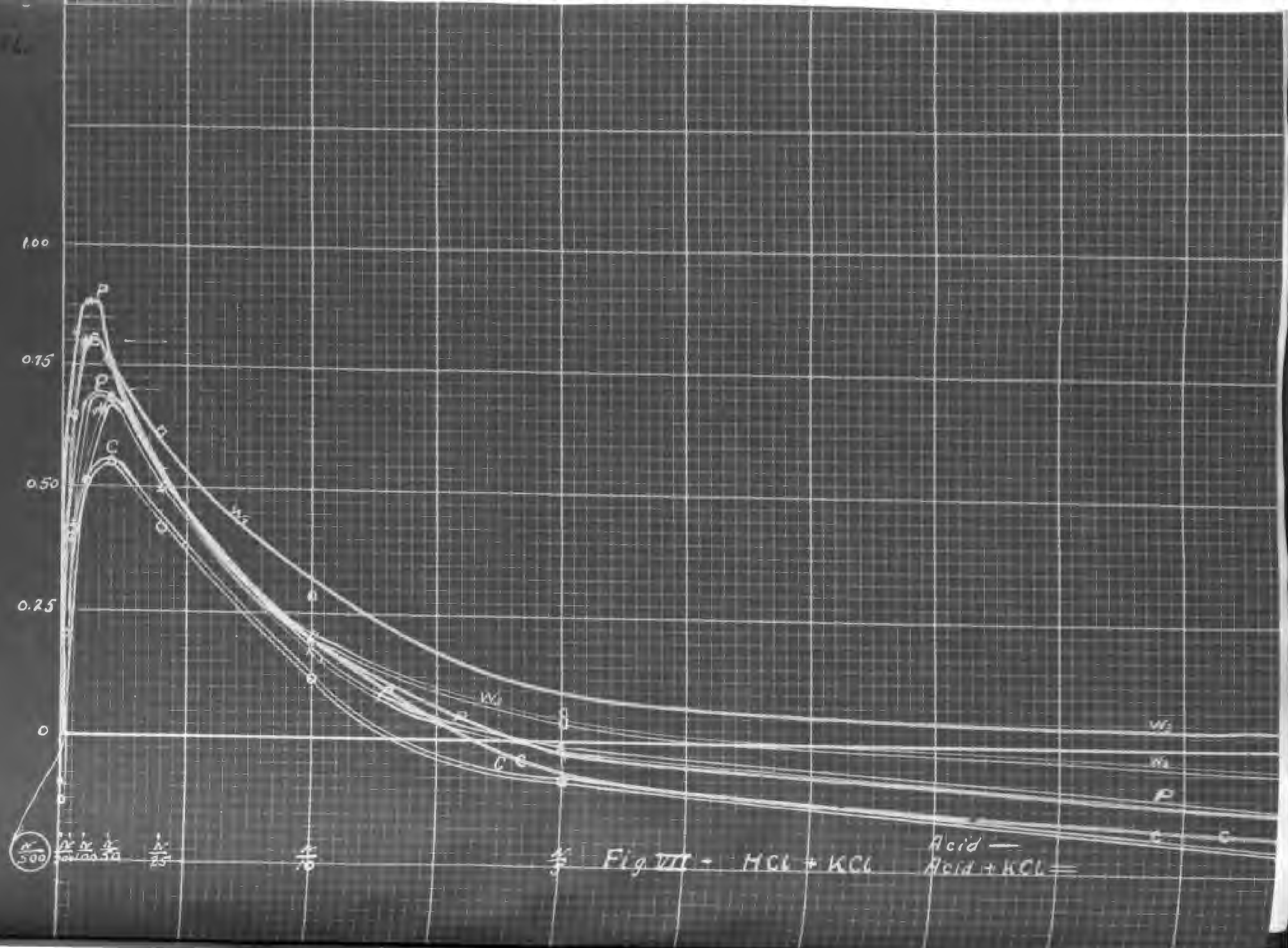

Fig VII - HCl + KCl

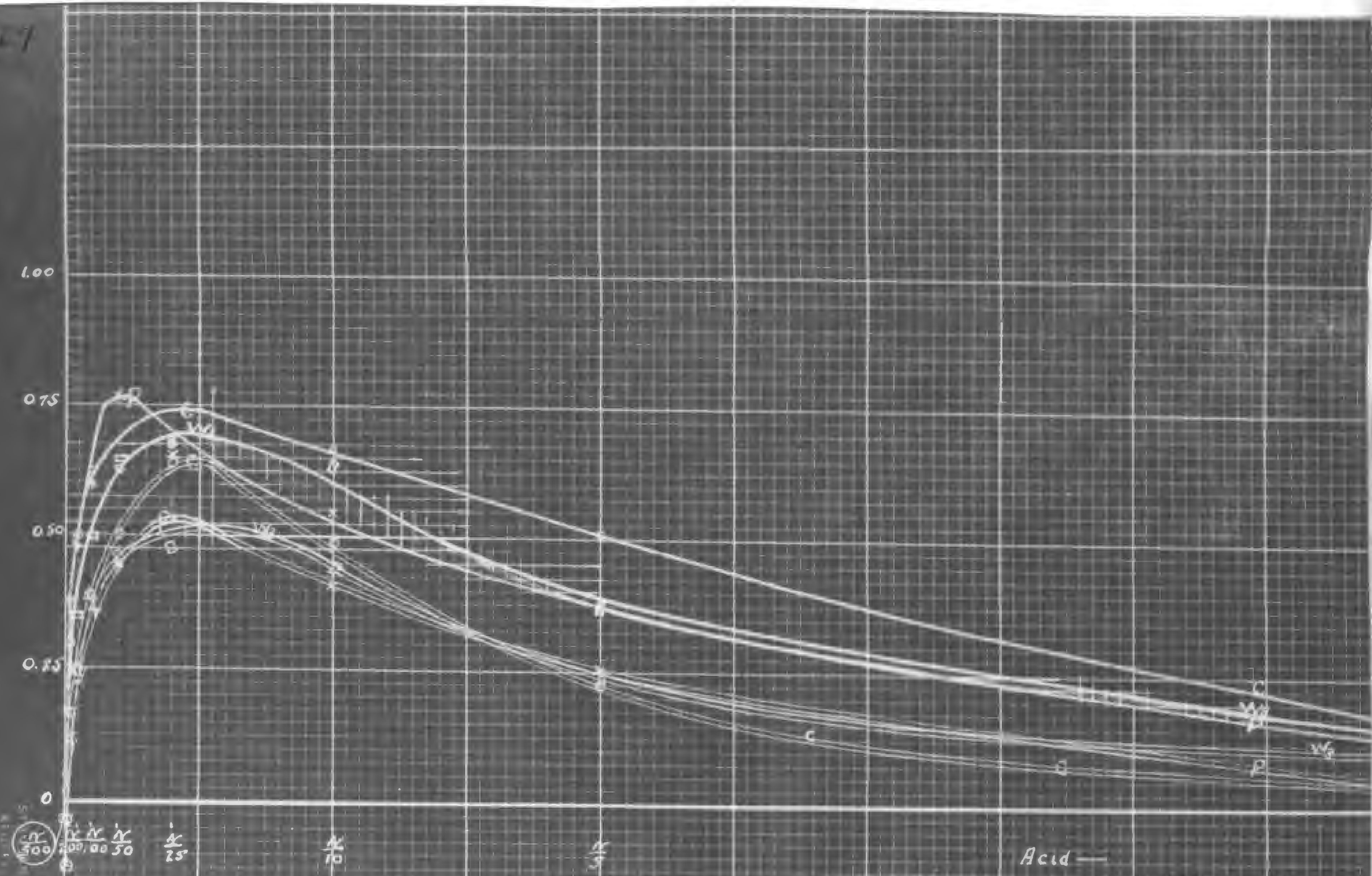

Fig. VIII – Oxalic Acid + KCL

III - DISCUSSION.

1. The relation between the quality of the various glutens and their degree of hydration. A study of tables I-IV confirm certain of the findings of Upson & Calvin, viz. "that gluten is an emulsoid colloid and shows all the properties of this class of compound" and that "Gluten absorbs water from dilute acid solutions, thereby losing its tenacity and ductility, becoming soft and gelatinous. The presence of small amounts of neutral salts in the dilute acid solutions inhibits water absorption by gluten." My data, however, do not support their third statement "that the bread-making qualities of dough made from wheat flours are dependent on the quantity and quality of the contained gluten. Quality of gluten is regulated by the kind and concentration of the acids and salts present in the dough. If the kinds and amounts of the acids and salts are such as to favor water absorption, the quality of the gluten will be poor, whereas the presence of acids and salts in such amounts as to tend to inhibit water absorption makes for an improved gluten," but on the contrary all the evidence is directly opposed to such a conclusion.

The above statement by Upson & Calvin seems to have only one interpretation i.e. that a "weak" gluten is "weak" because it is hydrated to a greater extent than is a "strong" gluten, and that in this respect, and in this respect only, does a "weak" gluten differ from a "strong" gluten. Upson & Calvin present data in their own bulletin which would have refuted this idea had they taken pains to make the necessary calculations. In table XXI are presented the percentages of moist gluten and dry gluten in the five flours which I have studied. If now we use these figures to calculate the percentage of water in the moist gluten, or in other words the amount of water imbibed by the dry gluten in preparing the gluten for the tests, we find the following figures:

	Water in wet gluten	Dry gluten in wet gluten	Calculated water content if glutens were hydrated equal to "P"	Difference of actual from hypothetical water content
	%	%	%	%
P	66.85	33.15		
C	67.37	32.63	65.82	+1.55
W_1	68.15	31.85	64.24	+3.89
W_2	66.00	34.00	68.56	-2.56
W_3	71.39	28.61	57.69	+13.70

Expressing these figures in the conventional form of grams water absorbed per gram of moist gluten and using the patent flour "P" as our standard we find that

"C" showed an excess of 0.015 gr. H_2O per gr. moist gluten over "P"
W_1 " " " " 0.039 " " " " " " " "
W_2 " a deficiency of 0.026 " " " " " " " "
W_3 " an excess of 0.137 " " " " " " " "

The figures for "C", "W_1", and "W_2" are certainly within experimental error and as such can have no significance, we must therefore conclude that these three glutens, although differing widely in "quality" and in physical properties from "P" were hydrated to almost exactly the same extent as was "P". However, the difference in moisture content of "W_3" gluten is probably significant. Let us therefore consider what effect this increased moisture content should have in the experiments in tables I - IV providing that the gluten had the same physical properties as "P".

"W3" contains 7.28 percent of dry gluten. The dry gluten of "P" composes 33.15 percent of the wet gluten, therefore the wet gluten of "W3" should weigh 21.96 grams at the same hydration as the gluten of "P". It actually did weigh 25.45 grams or an excess of 3.49 gr. of water based on a weight of 21.96 grams of moist gluten, this indicating an imbibition of 0.16 gr. H_2O per gram moist gluten (of "P" quality). This amount is entirely too small to account for the very marked differences in the physical properties of the two glutens and the only conclusion which remains possible is that there is an inherent difference in the glutens from "strong" and "weak" flours, that the colloidal properties of the glutens from the different flours are not identical and would not be identical even if the flours had the same salt and acid content.

These data are substantiated by the moist and dry gluten figures presented by Upson & Calvin, although these authors, as noted above, expressed the opinion that the difference between a "strong" and a "weak" gluten was due to its degree of hydration. Under table 12 on page 23 of their bulletin (Upson & Calvin 1916) are given the percentages of wet and dry gluten from several different mill streams of flour. Using carbondioxide free water as the washing agent, they give the percents of wet and dry gluten as follows:

	Wet gluten %	Dry gluten %
1st Middlings	23.5	7.1
3rd "	27.8	8.7
5th "	33.7	11.2
7th "	36.01	12.4

By making the same calculations on these different samples of gluten as was done on my own samples we have the following:

	Water in wet gluten	Dry gluten in wet gluten	Calculated water content if glutens were hydrated equal to 1st Middlings	Difference of actual from hypothetical water content
	%	%	%	%
1st Middlings	69.8	30.2		
3rd "	68.7	31.3	72.34	- 3.64
5th "	66.7	33.3	76.96	-10.26
7th "	65.1	34.9	80.66	-15.56

Again expressing these figures in grams of water absorbed per gram moist gluten and using the first middlings as the standard we find that

3rd Middlings shows a deficiency of 0.036 gr. H_2O per gr. moist gluten over 1st Middlings.

5th Middlings shows a deficiency of 0.103 gr. H_2O per gr. moist gluten over 1st Middlings.

7th Middlings shows a deficiency of 0.156 gr. H_2O per gr. moist gluten over 1st Middlings.

When a 0.5% NaCl solution was used as the washing agent they obtained the following results:

	Wet gluten	Dry gluten	Water in wet gluten	Dry gluten in wet gluten	Calculated water content if glutens were hydrated equal to 1st Middlings	Difference of actual from hypothetical water content.
	%	%	%	%	%	%
1st Middlings	32.1	9.4	70.7	29.3		
3rd "	34.5	10.3	70.1	29.9	72.2	-2.1
5th "	37.5	11.2	70.1	29.9	72.2	-2.1
7th "	38.6	12.0	68.9	31.1	75.0	-6.1

These figures expressed again in grams of water absorbed per gram of moist gluten, using the first middlings as the standard, give the following:

3rd middlings shows a deficiency of 0.021 gr. H_2O per gr. moist gluten over 1st middlings.

5th middlings shows a deficiency of 0.021 gr. H_2O per gr. moist gluten over 1st middlings.

7th middlings shows a deficiency of 0.061 gr. H_2O per gr. moist gluten over 1st middlings.

Upson & Calvin class the 7th Middlings as a "low grade" flour the gluten from which, according to their theory, we should expect to find hydrated to a greater degree than that from the first middlings. Such however is not the case. In both distilled water and in 0.5% NaCl the "weak" gluten appears to be less hydrated than is the "strong" gluten. To be sure four of the six differences are probably within the experimental error but it is probably significant that each of the six determinations shows a negative sign. Thus their own data refutes their idea that quality of gluten is regulated by the degree of imbibition and upholds my contention that quality of gluten is not determined by the amount of acids and salts in the flour but by the physico-chemical nature of the colloids present in the gluten.

Again these authors list data for a "patent" and a "low grade" flour in table 11 of their bulletin. These data when recalculated give

	Water in wet gluten	Dry gluten in wet gluten	Calculated H_2O content if gluten were equal to "Patent"	Difference between actual and hypothetical water content.
	%	%	%	%
"Patent"	67.9	32.1		
"Low Grade"	67.5	32.5	68.75	-1.25

or the low grade shows a deficiency of 0.0125 grams per gram of moist gluten over the patent gluten. This result is within the experimental error of the "patent" grade, but certainly does not support their theory as to the cause of "strong" and "weak" glutens.

I have devoted considerable space to the theory of Upson & Calvin because of its important bearing in a study such as I have made and I believe that I have presented sufficient evidence to show that it has no supporting evidence either in my own work or in any of their publications.On the contrary the data in both my tables and in their own is such as to prove the fallacyof their contention and to cause the theory to be definitely discarded.

Turning now to my own data as given in Tables I to IV inclusive, we find two noteworthy differences between the "strong" and "weak" glutens. These are 1. Rate of hydration and 2. Maximum capacity for hydration.

1. It will be observed that the different glutens, prepared and treated in exactly the same manner and for exactly the same interval of time, differ widely in their rate of hydration. For example in Table I 0.02N lactic acid, it is shown that 1 gram of moist gluten from "P" flour absorbed 1.14 grams of water while "W_1" gluten absorbed but 0.47 gram. At 0.04N, "P" gluten absorbed 1.25 grams of water while "W_1" absorbed only 0.51 gram. These examples are typical of other experiments in the tables and are so convincing that only one conclusion seems possible, *i.e.* that *a weak gluten has a much lower rate of hydration than has a strong gluten*.

2. There is moreover a marked difference in the maximum *degree of hydration* of the different glutens. In preliminary experiments it was found that discs of "P" gluten would retain their coherency and plasticity for as long as two hours in lactic acid and still be so cohesive that they could be easily removed from the acid solutions by means of small forceps although they had swelled

to three or four times their former size and had imbibed as much as 2.22 grams water per gram of moist gluten.

On the other hand the "weak" glutens "W_1", "W_2", and "W_3" became so badly dispersed when immersed in the concentrations of acids causing maximum imbibition that, in many instances, they could not be collected for weighingin even so short a time as one hour, although even at this point the weight of water absorbed must have been far below the quantity which the "P" gluten could imbibe and still remain coherent. We are forced to conclude, therefore, that not only does the weak gluten have a lower rate of imbibition than has the strong gluten, but that it also has a much lower maximum hydration capacity, or, in other words, <u>a "weak" gluten changes from a gel to a sol at a much lower degree of hydration than does a "strong" gluten</u>.

In short the difference between a "strong" and a "weak" gluten is that between a nearly perfect colloidal-gel with highly pronounced physico-chemical properties, such as pertain to colloids, and that of a colloidal-gel in which these properties are much less marked.

2. <u>Comparative measurements of the hydration capacity of the different glutens in various concentrations of hydrochloric, oxalic, lactic, and acetic acids.</u> The gluten prepared from patent flour ("P") when placed in either lactic, acetic, or hydrochloric acid shows a greater swelling than that of any of the other flours. This is followed by the "C" grade, then "W_2", and "W_1" respectively.

In oxalic there is a remarkable uniformity between all samples as is shown in Figure 4, where the imbibition of each flour at the various concentrations is graphically shown. The "C" grade exhibits a slightly greater imbibition but all are perhaps within experimental error. It is certainly of significance that such uniformity should exist, though just what factors are concerned is not at present apparent.

Of greater significance is the close resemblance in the amount of imbibition caused by hydrochloric and oxalic acids. Each exhibits an increase in the amount of hydration up to the maximum concentrations, 0.02 N and 0.04 N respectively, followed by a sharp decline. Both of these acids are highly ionizable. At N/10 strength the per cent of dissociation is as follows: hydrochloric 92%, oxalic 50%, acetic 1.3% (Smith), and lactic 3.8% (Landolt, Börnsteen Roth). At those concentrations causing greatest hydration of the gluten the ionization would be somewhat greater. Lactic and acetic acids, both of which are slightly ionized, even at the concentrations at which maximum hydration occurs, cause the greatest swelling of gluten. The underlying factors producing this phenomena are not apparent although it is possibly if not probably due to the fact that these acids furnish a hydrogen ion concentration more favorable to the imbibition of water by gluten. This possibility was noticed too late for the carrying out of a series of experiments tending to prove or disprove this hypothesis, but it is to be hoped that some one will attempt this in the future. In this connection it would be interesting to repeat some of the foregoing experiments using different dilutions of a very slightly ionized acid and noting the water imbibition. Boric acid would be excellent in this respect. The hydrogen ion concentration of the extracts from the various flours would in all probability throw light upon the problem.

3. Comparative measurements of the hydration capacity of the different glutens in various concentrations of hydrochloric, oxalic, lactic, and acetic acids to each concentration of which has been added .005 M of K Cl, KH_2PO_4, and $KHC_4H_4O_6$.

The imbibition of water by gluten in acid solution is lowered when neutral salts such as potassium chloride are added to the acid solution. This is readily seen by a reference to Tables V, IX, XIII, and XVII. The data of these tables are graphically represented in figures V to VIII inclusive. In these graphs are plotted the imbibition of the various glutens in acid solutions alone and likewise in the same concentration of acid to which K Cl, to an equivalent of 0.005 molar concentration, had been added.

In every instance the degree of imbibition is decreased by the potassium chloride, but it is of special importance to note that the general form of the curves remain unaltered. Thus the lactic and acetic acid curves still remain sharply differentiated from that of hydrochloric and oxalic acids. The greatest decrease in imbibition takes place in the acetic acid solutions, or in other words, the greatest decrease due to the salt, occurs in the acid solution which causes greatest imbibition by the gluten in the pure acid.

It is of interest to note that even in those instances where the gluten lost water in the acid solutions, e.g. hydrochloric acid figure VII, it lost more water in the acid plus potassium chloride. This loss in one instance amounted to almost 25% of the moist gluten.

It has not been possible to complete all of the laboratory work in time to allow for the preparation of all the graphs so that those for the various acids plus monobasic acid tartrate and monobasic potassium phosphate have not been plotted.

When gluten is placed in a 0.005 molar solution of monobasic potassium tartrate there is a small but perceptible amount of imbibition. Undoubtedly this is due to the fact that we are dealing with an acid salt which in aqueous solution, has a measurable H^+ concentration and which behaves both as a salt and as an acid. However, when the monobasic acid tartrate is added to the various acid solutions, there is observed in almost every instance a decrease of water absorbed.

In Table XVI it is worthy of note that "P" and "C" glutens in 0.002 N and 0.5 N hydrochloric acid, to which monobasic potassium tartrate is added, show a negative decrease, or an actual increase in water absorption. On the other hand the absorption in "W_3" gluten under the same conditions is retarded or there is an actual decrease in water imbibition. It is not possible at the present stage of the investigation to account with certainty for this difference.

Monobasic potassium phosphate when added to the solutions of the various acids seemed to retard imbibition of water to a less degree than did potassium chloride and monobasic potassium tartrate.

It is impossible to completely analyze these data without the necessary graphs, hence some significant difference may be present which has escaped my notice. This applies with equal force to the monobasic acid tartrate.

In general, however, the observation which others have made, that the addition of salts to acid solutions decrease the imbibition of water by colloids when placed in these solutions, is substantiated.

There does not seem to be any very great and consistent difference in the behavior of the various glutens in this regard, though "P" gluten seems somewhat more susceptible to the inhibiting effect of the various salts. Each gluten seems to follow very closely the same form of curve as is given by the "no salt" checks, but at a lower level of water imbibition.

4. Baking Tests and Flour Analyses.

In the foregoing experiments and discussion, considerable attention has been given to the effect of acids and salts on glutens prepared from "strong" and "weak" flours and I believe it has been clearly shown that the determining factor in flour strength is not the concentration of soluble acids and salts which are originally present.

Further evidence, however, that "quality" in flours is not determined by the soluble acid and salt content is again presented in table XXI. From the data therein given, it is to be observed that the patent flour ranks first in baking quality. It absorbs more water in the doughing process, producing a dough much more coherent and elastic as is shown by the maximum expansion of the dough during the process of fermentation, and produces a loaf of the largest size and of the best texture.

It will also be noted that the patent flour is somewhat lower in its total and soluble ash content, and electrical conductivity. However, the differences between the patent flour, the flour with the strong gluten and the "W_3 flour, the flour with much weaker gluten, give values for ash on dry flour, soluble ash, and specific conductivity of the flour extract, all of which are within experimental error of each other, an observation which confirms the previously expressed idea, that "strength" or "weakness" of gluten is an inherent factor of the flour proteins, and is not determined to any great extent by the inorganic material present in the flour.

The soluble ash and specific conductivity are almost parallel to each other in every case. This was to be expected since both determinations were made on the same flour extracts.

The bread baked from the weak flours was of poor texture. In each case the dough lacked the coherency and elasticity necessary to produce "large well piled" loaves. This is without doubt partially accounted for by the lower gluten content of these flours but the work with the various gluten reported upon in another part of this paper leads me to believe that much of this difference is due to a difference in the character of the gluten itself.

IV. Summary

In this paper are presented data showing the increase or decrease of water imbibition caused by immersing weighed discs of gluten from five selected flours in solutions of lactic, acetic hydrochloric, and oxalic acids of various concentrations both with and without the addition of 0.005 molar concentrations of potassium chloride, monobasic potassium phosphate and monobasic potassium tartrate.

Data have also been presented showing different flour analyses shch as ash on dry flour, soluble ash, specific conductivity of flour extract, percent of moist gluten, percent of dry gluten, percent of ash in dry gluten, and baking tests.

From a study of these data, I have drawn the following conclusions:

(1). Although the moist glutens from these flours differ widely in "quality" and in physical properties, they are hydrated to almost exactly the same extent when washed free of starch in the usual manner.

(2). The acid and salt content of the flours are not responsible for the difference between a "strong" and "weak" gluten.

(3). There is an inherent difference in the glutens from the "strong" and "weak" flours. The colloidal properties of the glutens from the different flours are not identical and would not be identical even if the flours had originally had the same acid and salt content.

(4). A weak gluten has a much lower rate of hydration than has a strong gluten.

(5). A weak gluten has a much lower maximum hydration capacity than has a strong gluten, changing from a gel to a sol at a much lower degree of hydration.

(6). The difference between a strong and weak gluten is that between a nearly perfect colloidal-gel with highly pronounced physico-chemical properties, such as pertain to colloids, and that of a colloidal-gel in which these properties are much less marked.

(7). Two types of imbibition curves were observed. These are apparently caused by H^+ concentration of the acids used. The greater imbibition takes place in those acids having the lower H^+ concentration.

(8). Inorganic salts, when added to an acid solution lower the water imbibition of gluten when placed in such solutions over that in the acid alone.

(9). No consistent relation between the flour analyses could be found which would satisfactorily explain the difference between strong and weak flours. All the data point to the fact that there must be a difference in the kind of colloids.

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