

6-1940

The viscosity of silicic acid gels

William George Gormley
Union College - Schenectady, NY

Follow this and additional works at: <https://digitalworks.union.edu/theses>



Part of the [Chemistry Commons](#)

Recommended Citation

Gormley, William George, "The viscosity of silicic acid gels" (1940). *Honors Theses*. 1846.
<https://digitalworks.union.edu/theses/1846>

This Open Access is brought to you for free and open access by the Student Work at Union | Digital Works. It has been accepted for inclusion in Honors Theses by an authorized administrator of Union | Digital Works. For more information, please contact digitalworks@union.edu.

THE VISCOSITY OF SILICIC ACID GELS

THE VISCOSITY OF SILICIC ACID GELS

A thesis presented to the Department of
Chemistry of Union College in partial fulfillment
of the requirements for the degree of Bachelor of
Science in Chemistry, by

William Gormley

Approved by Charles B. Sturd

May 21, 1940

INDEX

Presentation

1. Introduction
3. Historical
5. Procedure
8. Results and Discussion
11. Graphs
17. Photographs
18. Data
39. Summary
40. Bibliography

INTRODUCTION

Gelation is that phenomenon in which the entire system of both dispersion medium and dispersed substance solidify into an apparently homogeneous, solid mass. Upon the assumption that a jelly consists of myriads of hydrous particles that have become enmeshed into a network that entrains liquids, it follows that any substance should form a jelly when a suitable amount of a highly dispersed substance is precipitated provided that the particles adsorb the dispersing medium very strongly. The process of gelation differs macroscopically from flocculation in that flocculation presents a separation of the dispersed substance. It has been proposed¹ that gelation is flocculation in which the dispersed substance is highly hydrated. We will differentiate two types of gelation processes. Gelatin and agar-agar gelatinize through a decrease in temperature, and we will refer to this as temperature-gelation. Aluminum oxide, cerium dioxide, and silica gelatinize upon addition of a sufficient amount of electrolyte, and we will refer to this as electrolyte-gelation. The factors governing the gelation of hydrated silica or colloidal silicic acid have been summarized by Flemming², Hurd and Carver³, and Hurd and Hallstrom⁴, as:

1. acid concentration and type of acid
2. pH
3. silica concentration
4. temperature
5. agitation
6. added soluble material
7. type of silicate

2

We have investigated factors (1) and (2) while keeping the other factors as nearly constant as possible. It is, of course, impossible to vary the acid concentration without also varying factor (6) since the varying of the acid also varies the content of the sodium salt of that acid.

For this investigation the Ostwald viscometer was used. Prasad, Mehta, and Desai⁵ have reported the successful use of the viscometer in gelation processes, and Hurd and Santora⁶ also used the instrument with success. However, in order to come to a decision on the general applicability of the viscometer in following the gelation process, a careful re-examination of the question with a view to the structure of the gel became imperative.

HISTORICAL

Prasad, Mehta and Desai⁵ used Scarpa's modification of Ostwald's viscometer to measure the viscosities of gel mixtures during gelation. Hurd and Fraser⁷ examined both the Ostwald and the Stormer type of viscometer and concluded that the Ostwald type had certain advantages because of its simplicity although they admitted that the Stormer type had greater possibilities. Dahr and Chakravarty⁸ examined the effect of electrolytes on the setting of gel mixtures, and Hurd and Santora⁶ used the Ostwald viscometer for the same work. They report the viscometer to be satisfactory. Krüyt¹ points out that Poiseuille's law of viscosity does not apply upon gelation. A. Einstein and E. Hatschek have devised an equation that permits the evaluation of the viscosity of a dispersed system provided that: (1) the particles are spherical and not deformable; (2) the dimensions of the particles are large compared to the molecular dimensions of the dispersion medium; (3) the particles must be small in comparison to the measuring instrument; and (4) movement of the dispersion medium in the direct vicinity of the particles may not be influenced by presence of other particles. Fulfillment of these conditions has been found to be extremely rare, and is certainly not present in silica gels, although the formula has been used to calculate hydration.

Upon the structure of silica gels, much has been written and little has been determined. Bogue⁹ reports that in solutions of 37-18.5% of $\text{Na}_2\text{O} \cdot 3.3 \text{SiO}_2$, there are myriads of tiny particles clearly distinguishable under the ultra microscope. Butschli¹⁹ treated the gel with a mixture of chloroform and cedarwood oil and, allowing the chloroform to evaporate, obtained a structure which was visible under the microscope. He concluded that the gel was made up of micelles. Zsigmondy¹⁰ concluded that the gel contains a mul-

• titude of amicroscopic pores; he stated that Butschli's results were caused by alternate portions of gel either saturated with liquid or from which liquid had been evaporated. Bachmann¹¹ studied the gelation of gelatin with the ultra microscope. On the basis of his observations, he concluded that the process of gelation consists of the union of primary particles into larger aggregates. The dispersion medium is thus trapped in the capillary space. Studying soap solutions, Bachmann¹² has shown that when they set to a jelly, long threads are formed. We took micro photographs of the etch patterns of NaOH on silica gels and obtained photographs very similar to those obtained by Bachmann when he worked with gelatin gels.

PROCEDURE

Preparation of Solutions

A quantity of E brand sodium silicate, a product of the Philadelphia Quartz Company, was diluted with recently boiled, distilled water. This silicate has a $\text{Na}_2\text{O}:\text{SiO}_2$ ratio of 1:3.25. The resulting solution was titrated with standard sulfuric acid and its equivalent as NaOH determined as 1.375 using methyl orange as an indicator.

Three acids were prepared. Acetic acid was prepared by diluting 99.5% glacial acetic acid with recently boiled distilled water. Sulfuric and hydrochloric acids were prepared by diluting reagent grades of the concentrated acids in the above manner. Their normalities as determined by titration with recently standardized NaOH solution using phenolphthalein as the indicator were:

$$\text{HAc} \quad = \quad 1.8603 \text{ N}$$

$$\text{H}_2\text{SO}_4 \quad = \quad .8150 \text{ N}$$

$$\text{HCl} \quad = \quad .5080 \text{ N}$$

Temperature Control

In order to control the temperature, a large glass reservoir bath fitted with a de Khotinsky bi-metal thermostat control with a blade heater was used. The transparency of the reservoir is essential for viscosity measurements. Since the temperature worked at was approximately room temperature, this thermostat gave quite satisfactory results, that is $.1^\circ$.

pH Measurements

Hurd and Griffeth¹³ have shown that the quinhydrone potentiometer gave reliable results for the measurements of pH of silica gels in the acid region. Most of the measurements were made in the acid region. A calomel cell with saturated KCl and a platinum wire electrode were prepared as sug-

gested in Daniels, Mathews, and Williams¹⁴. Those gels above the range of the quinhydrone potentiometer are marked alkaline gel on the curve.

Mixing of Solutions

It is essential that the solutions be mixed uniformly and quickly. In the procedure, the silicate solution was measured into a dry, clean 100 c.c. beaker with a pipette. The acid and the third constituent were measured into a second similar beaker, with a burette. The two solutions were brought to the temperature of the thermostat. The silicate solution was poured into the acid and the two were mixed by pouring back and forth rapidly. Viscosity measurements were then made.

Time Measurements

Two accurate stop watches were used. One was started when the solutions were first mixed. The other was used to determine time of flow in the viscometer.

Ostwald Viscometer

The Ostwald viscometer is essentially a U-tube with a capillary tube in one arm. Above the capillary tube is a small bulb of about 2 c.c. volume. There are two reference marks: one above the bulb, and one below. A definite volume of the liquid is introduced into one arm and sucked up above the top reference mark. The time for the meniscus of the liquid to pass the two reference points is determined with a stop watch. The measurement of the absolute viscosity of gel mixtures is impossible with this instrument. The measurements were found to depend on the viscometer used. The viscometer used herein had a large capillary bore and was calibrated with distilled water and pure glycerine.

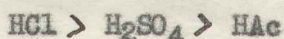
Photographing of Gels

It was observed while cleaning gels from viscometers that concentrated sodium hydroxide gives a peculiar pattern as it dissolves a gel. This

is visible with a magnifying glass as a mass of dot-like material. In order to examine this phenomenon more closely, we photographed the gels with the micro photographic arrangement of the Biology Department. This was done through the generous cooperation of Dr. Allan C. Scott of that department. The gels were set in Petrie dishes and concentrated NaOH was poured over them to cover the surface. Light was directed from above to the surface and the photographs taken from above. A black background was placed under the dishes. In order to slow down the rate of dissolution, the dishes were set on ice cakes and a water filter was placed between the light and the gels. This arrangement worked exceedingly well in slowing down the dissolution so that several photographs could be taken. The pictures contained herein are approximately ten times actual size. The gel used for the photographs had a pH of approximately 6.

RESULTS AND DISCUSSION

Several viscometers were used and the results stated by Krut¹ and reaffirmed by the data of Hurd and Santora⁶ were confirmed. In every case the viscosity depends on the viscometer used; thus on the size of the capillary and the pressure head of the tube. Not only does the viscosity vary but also the time of set of the gel depends upon the instrument used to measure it. This is clearly shown by curves presented by Hurd and Santora⁶. In no case did the time of set as determined by them agree with the time of set as determined by the rod method used by Hurd and Letteron¹⁵. Consistent results are obtainable only when one viscometer is used throughout the entire work. From the curves (Plate 1 and 2 for HCl; Plate 3 and 4 for H₂SO₄; and Plate 5 and 6 for HAc) it is obvious that the rate of setting of the gels of the three acids used is:



This is consistent with the results obtained by Hurd and Santora⁶ and Dahr and Chakravarty⁸, when it is considered that the acid added also determines the type of salt which will be present in the gel.

The pH of the gels changed during gelation. This change in acid gels is generally to higher pH values; however, this is not always the case and, at present, it is not possible to predict how the pH will change.

I present the photographs as an indication of gel structure. Since NaOH dissolves the gels, it is rational to think of this dissolution as the opposite process of gelation. Following the figures from 1 to 4, we see the gel being disintegrated. In figure 1, the large striations appear on the surface which spread out cutting the whole gel into small sections. In figure 2, these large striations have largely disappeared although vestiges remain. In figure 2, more or less tubular-shaped structures are evident and

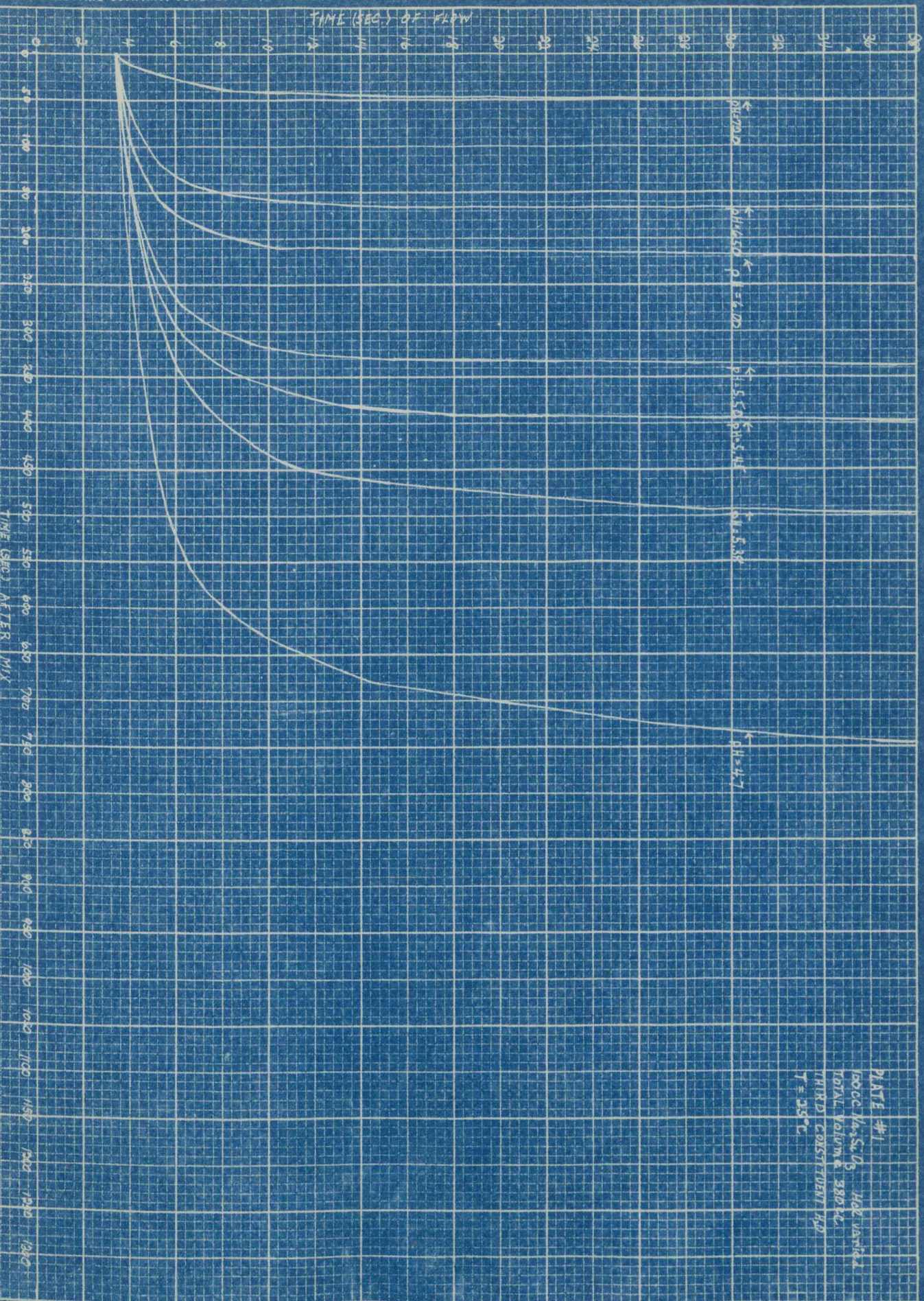
9

these are being cut by wedge-shaped notches starting from each side. This division is by no means haphazard. In figure 3, the process is continued, and in figure 4, we have almost complete division into a mass of particles. In the lower corner of figure 4, the solution is seen. Here the particles have become very small and finally they disappear. In figures 1 and 2, the camera was in the same position. Figures 3 and 4 are in different positions.

As remarked before, Bogue⁹ has observed particles under the ultra microscope in silica sols. If these particles become hydrated, they will increase immensely in size until the entire mixture becomes immobile. The liquid remaining in the dispersion medium will become entrained in the gel structure, and the whole will set or gel. There are two complementary processes taking place. The increase of the size of the particles through hydration and the decrease of the amount of liquid of the dispersion to the hydrated particles. Thus both processes tend to immobilize the whole. An immense increase of the size of the particles would have small effect on the viscosity if the original particles were very small. However, when the particle size becomes comparable to the size of the capillary tube, even a small relative change in size would have an immense effect on the viscosity. It is probable, therefore, that gelation does not proceed as the viscosity curves would indicate, but occurs gradually. This would explain why different values of gelation time are obtained with every viscometer used. As soon as the particle size becomes commensurate with the capillary size, an immense increase in apparent viscosity occurs.

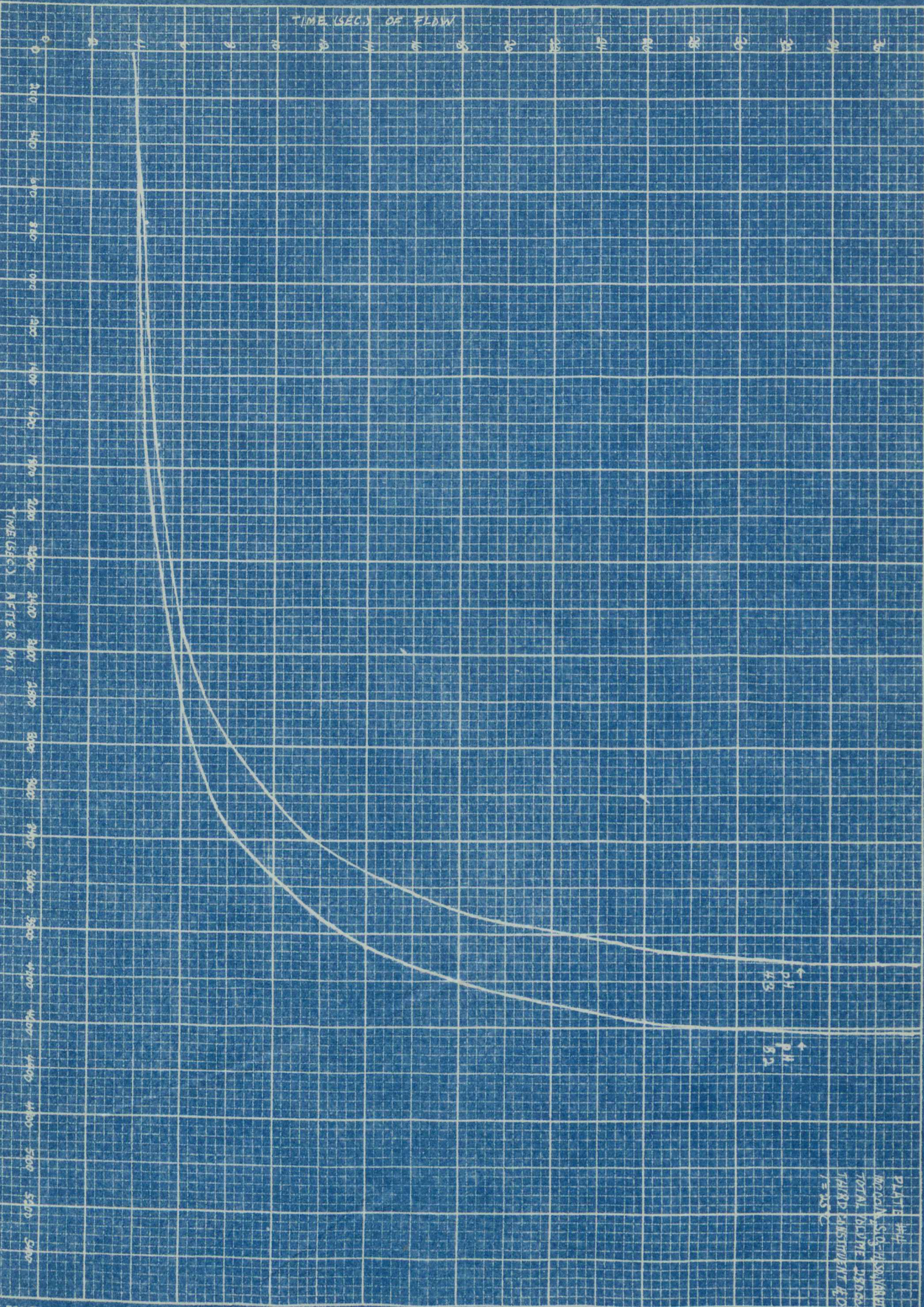
As previously mentioned, it has been proposed¹ that we think of gelation as flocculation in which the particles are highly hydrated. Evidence for this view is obtained from alkaline gels which are too alkaline to set. If these gels are allowed to stand for a few weeks, a precipitate

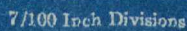
is obtained. This might be the precipitation of particles whose hydration has been limited by the high pH.

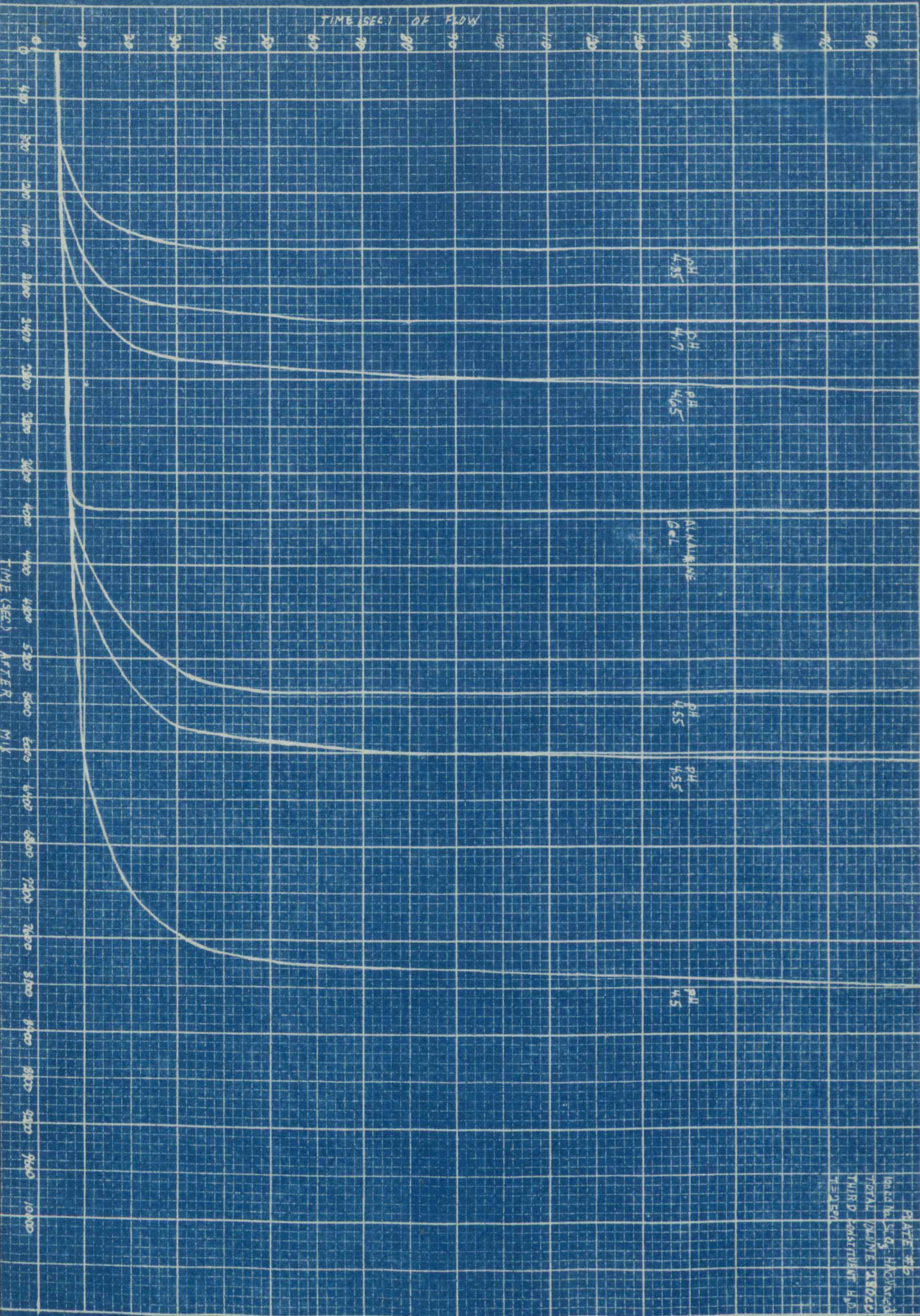












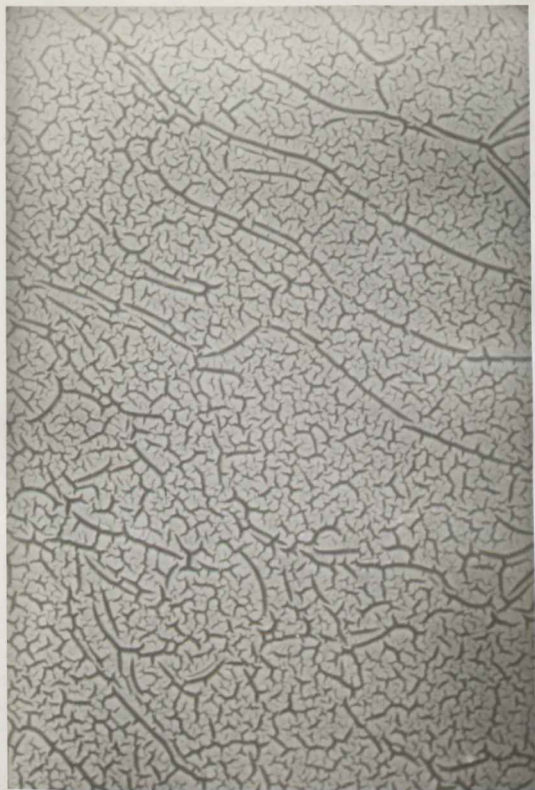


Figure 1

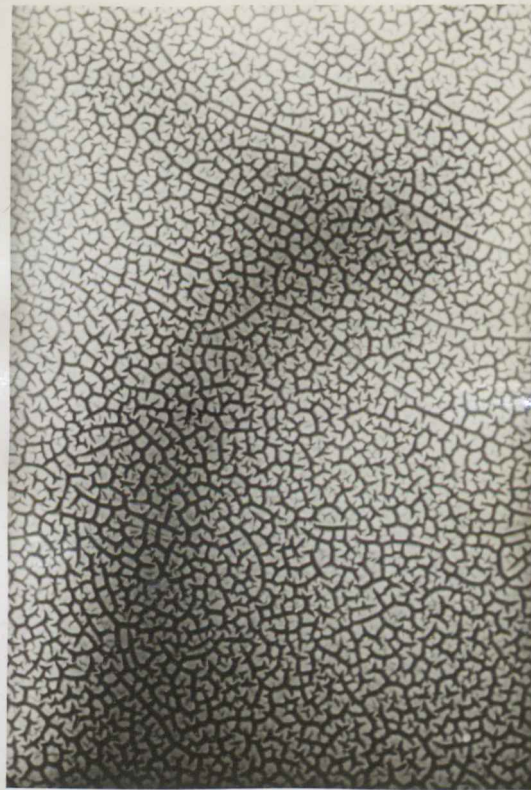


Figure 2

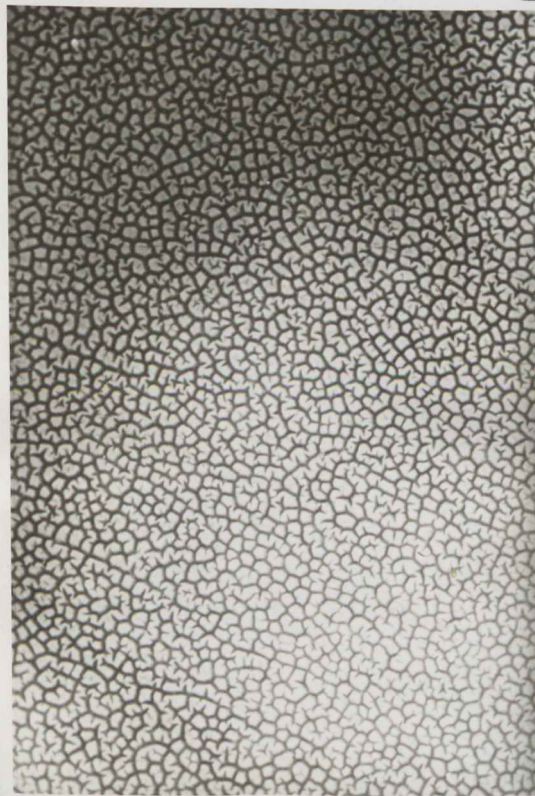


Figure 3

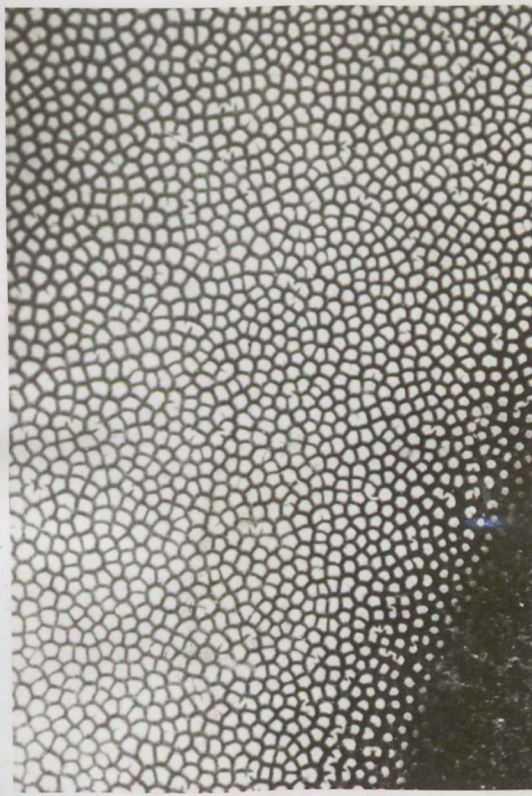


Figure 4

DATA

Calibration of Viscometers

Viscometer 1	Water 23.8° C.	<u>Time of Flow</u>
		3.0
		3.1
		3.0
		3.0
		<u>3.0</u>
	Average	3.0 sec.

Viscosity of water at 23.8° C. 9.20 millipoise
(Taken from data of Bingham and Jackson)

Glycerine 23.8° C. 829.6 sec.

Viscosity of glycerine at 23.8° C. 8.2 poise
(Taken from data of Schottner)

Viscometer 2	Water 24.7° C.	<u>Time of Flow</u>
		3.0
		3.0
		2.8
		3.0
		<u>3.1</u>
	Average	2.9 sec.

Viscosity of water at 24.7° C. 9.00 millipoise
(Taken from data of Bingham and Jackson)

Glycerine 24.7° C. 810.0 sec.

Viscosity of glycerine 24.7° C. 5.3 poise
(Taken from data of Schottner)

Density of Silicate solution as determined with Westphal

Balance at 25° C. 1.135 g/c.c.

PLATE I

Curve I

100 c.c. Na_2SiO_3
270 c.c. HCl
10 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time flow (sec.)</u>	<u>Potentiometer</u>
30	4.4	
45	15.0	-5
65	set	
300		-23
1020		- 28

Curve II

100 c.c. Na_2SiO_3
275 c.c. HCl
5 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time flow (sec.)</u>	<u>Potentiometer</u>
25	3.6	
60	4.0	
120	5.4	
165	15.7	-70
180	set	

Curve III

100 c.c. Na_2SiO_3
275 c.c. HCl
4 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time flow (sec.)</u>	<u>Potentiometer</u>
20	3.6	-115
90	4.0	
145	4.8	-115
165	5.6	
195	7.2	-98
210	10.4	
240	set	-98

Plate I - ContinuedCurve IV

100 c.c. Na_2SiO_3
 277 c.c. HCl
 3 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
25	3.4	
125		-125
170	4.4	
200	4.7	
230	5.2	
265	6.0	
310	9.0	
380	15.4	
420	set	-127

Curve V

100 c.c. Na_2SiO_3
 278 c.c. HCl
 2 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
45	4.0	
120		-124
150	4.2	
180	4.4	
210		-127
225	4.8	
260	5.2	
280	5.6	
305	6.4	
330	7.4	-127
365	11.0	
390	18.0	
420	set	-127

Plate I - ContinuedCurve VI

100 c.c. Na_2SiO_3
 277 c.c. HCl
 3 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time flow (sec.)</u>	<u>Potentiometer</u>
30	3.6	
75		-124
105	3.8	
150		-130
180	4.0	
215	4.4	
230	4.5	
265	4.7	
290	5.2	
320	5.8	-133
350	6.4	
380	7.4	

Curve VII

100 c.c. Na_2SiO_3
 277 c.c. HCl
 3 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
120		-153
150	3.8	
170	4.0	
210		-140
315	4.5	
370	4.6	
390		-137
440	5.1	
480	5.6	
505	5.8	
530	6.8	
600	7.7	
620	8.2	
645	11.2	
680	14.6	
750	66.4	
840		-133

PLATE IICurve I

100 c.c. Na_2SiO_3
 277.5 c.c. HCl
 2.5 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of Flow (sec.)</u>	<u>Potentiometer</u>
25	5.6	
90		-207
120	5.6	-227
1190	3.6	
4020	6.0	
4240	6.4	-217
4440	7.2	
4530	7.6	
4680	8.6	-218
4950	11.4	
5010	12.1	
5055	12.8	
5110	14.5	
5160	15.8	
5200	17.4	
5250	20.2	
5295	25.0	
5370	41.7	
5445	96.2	
5700	240 (app.)	-212

PLATE IIICurve I

100 c.c. Na_2SiO_3
 189 c.c. H_2SO_4
 31 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow</u>	<u>Potentiometer</u>
20		15

Plate III - ContinuedCurve II

100 c.c. Na_2SiO_3
 169 c.c. H_2SO_4
 31 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
35		-26

Curve III

100 c.c. Na_2SiO_3
 169 c.c. H_2SO_4
 31 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
45	6.0	-80
105		-80

Curve IV

100 c.c. Na_2SiO_3
 170.5 c.c. H_2SO_4
 29.5 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
	4.2	-193
30	7.2	
120	10.4	-151
150		
180		-115
585		

Curve V

100 c.c. Na_2SiO_3
 169 c.c. H_2SO_4
 31 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
34	4.4	-144
90	6.6	
140	9.0	
210	14.5	-120
230	19.5	
245	26.0	

Plate III - ContinuedCurve VI

100 c.c. Na_2SiO_3
 170.5 c.c. H_2SO_4
 29.5 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
80	4.2	
120		-112
150	5.1	
180	5.7	
210		-127
225	7.7	
230	10.2	
305	23.0	
540		-127

Curve VII

100 c.c. Na_2SiO_3
 171.5 c.c. H_2SO_4
 28.5 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
100	4.2	
150		-135
190	4.7	
215	4.8	
240		-137
280	5.2	
285	5.6	
325	6.2	
330		-137
380	7.4	
405	8.8	
435	10.6	
480	14.3	
495	25.8	

Plate III - ContinuedCurve VIII

100 c.c. Na_2SiO_3
 170 c.c. H_2SO_4
 30 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
55	4.1	-145
65	4.1	
85	4.2	
120	4.2	
175	4.4	
200	4.2	-140
240	4.5	
270	4.5	
300	4.6	
335	4.8	
380	4.8	
390	5.2	-145
420	5.3	
450	5.4	
480	5.7	
525	6.2	
560	6.6	-140
585	7.0	
615	8.0	
640	8.8	
675	10.0	
700	11.9	
755	14.6	-140
780	22.0	

Plate III - ContinuedCurve IX

100 c.c. Na_2SiO_3
 171 c.c. H_2SO_4
 29 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
50	4.0	
130	4.2	-152
165	4.2	
210	4.5	-157
360	4.8	-
530	5.0	
585	5.2	
610	5.4	
635	5.4	
675	5.6	
735	6.2	
780	6.6	-153
820	7.3	-156
850	7.7	
885	8.4	
910	9.0	-153
935	9.8	
970	11.0	-153
995	12.3	
1050	14.3	
1060	16.8	-156
1095	21.5	
1140	34.1	-153

PLATE IVCurve I

100 c.c. H_2SiO_3
 175 c.c. H_2SO_4
 27 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
35	3.8	
80		-185
120	4.0	
170	4.0	
300	4.5	
750		-185
795	4.5	
980		-180
1035	4.6	
1205	4.8	-185
1560	5.0	
1745	5.3	-183
1940	5.6	
2170	5.5	-187
2340	5.6	
2385	5.8	
2480	6.0	-188
2540	6.4	
2580	6.3	
2745	6.8	
2810	7.0	
2890	7.8	-193
3040	8.2	
3100	8.7	
3240	9.6	
3340	10.8	
3405	11.6	
3440	12.2	
3480	12.9	
3500	15.3	
3640	16.2	
3675	17.5	
3730	19.5	
3770	21.2	
3825	24.0	
3865	27.0	
3930	32.4	
3975	52.5	-195

Plate IV - ContinuedCurve II

100 c.c. H_2SiO_3
 170.5 c.c. H_2SO_4
 29.5 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
25	4.0	
60		27
80	4.0	
105	4.0	
120		27
150	4.0	
200	4.0	
240	4.0	
280	4.0	
320	4.0	
360		30
390	4.0	
540	4.0	
810	4.0	
980	4.3	
990	4.3	
1175	4.2	
1570	4.4	27
1720	4.6	
1830	4.7	
1980	4.8	
2175	4.8	
2280	5.1	
2335	5.2	
2355	5.3	
2440	5.4	25
2680	5.8	
2800	6.1	
2835	6.2	
2880	6.3	
2940	6.4	
3015	6.6	
3085	7.0	
3180	7.2	
3200	7.5	
3500	8.0	
3535	8.2	
3490	9.0	
3580	9.6	
3590	10.0	
3630	10.4	
3680	11.1	
3725	11.8	

Plate IV - ContinuedCurve II (Continued)

3790	13.8	
3835	14.0	
3900	15.0	
3945	18.1	
3985	17.2	
4050	18.6	
4065	20.3	
4100	22.0	
4155	24.9	
4195	28.6	
4320		27
4380		15

PLATE VCurve I

100 c.c. Na_2SiO_3
 85 c.c. HAc
 95 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
37	4.6	-140
65	4.8	-137
85	5.0	
125	5.4	-137.5
145	5.7	-137
163	6.0	
185	6.4	
205	7.0	-136
225	8.2	
250	9.2	
280	11.8	
310	17.5	
345	25.0	-136

Curve II

100 c.c. Na_2SiO_3
 83.5 c.c. HAc
 96.5 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
80	7.2	-177
120	7.4	-155
140	7.8	-140
185	9.0	-133
210	10.2	-130
255	12.5	-130
300	17.5	

Plate V -- ContinuedCurve III

100 c.c. Na_2SiO_3
 91 c.c. HAc
 89 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
30	4.0	-147
150	5.0	
220	5.8	
250	7.2	
270	7.6	-145
300	8.4	
330	9.2	-145
350	9.6	
400	12.4	
415	14.0	
435	18.0	-145

Curve IV

100 c.c. Na_2SiO_3
 95 c.c. HAc
 85 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
50	4.2	-155
75	4.4	
120	4.6	-155
200	5.3	
250	5.8	
280	6.0	-150
310	6.3	-150
340	6.6	-150
410	7.2	
450	7.6	
540	9.6	
580	10.8	
580	set	-150

24

Plate V - Continued

Curve V

100 c.c. Na_2SiO_3
100 c.c. HAc
80 c.c. H_2O

Viscometer 2

<u>Time after mixing (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
90	4.6	-170
130	4.6	
165	4.8	
180	4.8	
220	4.8	-155
250	4.8	
300	4.9	
360	5.2	
405	5.3	
430	5.6	-180
490	5.8	
555	6.0	
615	6.4	
680	7.0	
720	7.0	-155
780	8.0	-155
810	8.5	
850	9.2	
880	10.0	
920	11.0	-155
970	12.8	
1020	15.7	
1080	19.4	-154
1125	27.0	

Curve VI

100 c.c. Na_2SiO_3
20 c.c. HAc
180 c.c. H_2O

Viscometer 1

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
60	5.4	
115	5.7	higher than 100
145	5.4	
180	5.6	
240	5.6	
690	5.8	
755	6.0	
765	6.0	
780	6.0	
1030	6.4	
1080	6.4	
1215	7.5	
1255	8.2	
1285	9.0	
1380	12.0	
1370	17.8	

PLATE VICurve I

100 c.c. Na_2SiO_3
 111 c.c. HAc
 89 c.c. H_2O

Viscometer 1

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
90	4.6	-158
150	4.8	
200	4.8	
245	5.0	
320	5.2	
450	5.2	
570	5.4	
615	5.6	-155
660	5.8	
780	6.2	
870	6.6	
975	7.2	
1035	7.4	
1080	8.0	
1125	8.5	
1155	8.8	-155
1200	9.2	
1230	9.4	
1250	10.2	
1305	10.8	
1350	11.9	
1380	12.8	-155
1410	14.2	
1450	15.7	
1500	18.3	
1560	22.6	
1620	28.0	
1690	39.1	-155

Plate VI - ContinuedCurve II

100 c.c. Na_2SiO_3
 130 c.c. H_2O
 50 c.c. H_2O

Viscometer 1

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
90	4.0	-176
345	4.2	
540	4.4	
650	4.7	
785	4.9	
885	5.0	
1025	5.2	
1160	5.4	
1250	5.6	
1290	6.0	
1390	6.2	
1420	6.6	-175
1500	6.8	
1545	7.2	
1585	7.4	
1620	8.0	
1665	8.3	
1705	8.8	
1745	9.2	
1780	9.6	-175
1820	10.4	
1860	11.2	
1905	12.3	
1940	13.2	
1995	14.3	
2030	16.2	
2075	18.6	
2115	21.2	
2170	25.3	
2210	31.7	
2265	51.7	-175

Plate VI - Continued

Curve III

100 c.c. Na_2SiO_3
125 c.c. HAc
55 c.c. H_2O

Viscometer 1

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
90	4.3	-186
315	4.4	
425	4.6	-170
550	4.7	
750	4.8	
785	4.9	
870	5.1	
1020	5.3	
1230	5.4	
1410	5.8	-178
1500	6.2	
1560	6.2	
1620	6.3	
1680	6.8	
1710	7.2	-180
1750	7.4	
1800	7.6	
1845	7.8	
1905	8.2	
1950	8.8	
2000	9.0	-180
2040	9.4	
2070	9.8	
2110	10.2	
2145	10.8	
2190	11.4	
2220	12.0	
2265	12.4	
2295	13.3	
2340	14.4	-180
2385	15.9	
2415	17.3	
2470	19.2	
2520	21.7	
2565	25.6	
2625	30.6	
2670	39.0	
2745	95.0	-180

Plate VI - ContinuedCurve IV

100 c.c. Na_2SiO_3
 19 c.c. HAc
 161 c.c. H_2O

Viscometer 1

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
45	5.2	higher than 100
110	5.6	
1200	5.8	
2400	5.6	
3150	5.8	
3220	6.0	
3360	6.2	
3400	6.2	
3505	6.4	
3545	6.6	
3575	6.8	
3635	7.0	
3690	7.4	
3720	7.8	
3750	8.4	
3780	8.8	
3810	9.7	
3840	10.4	
3865	11.4	
3905	12.4	
3930	13.8	

Curve V

100 c.c. Na_2SiO_3
 150 c.c. HAc
 80 c.c. H_2O

Viscometer 1

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
150	4.4	-215
1595	4.8	
1985	5.0	
2480	5.2	
2610	5.4	
2830	5.6	-200
3080	6.0	
3325	6.5	
3530	7.0	
3620	7.2	
3710	7.4	-190
3780	7.6	
3840	7.8	
3900	8.0	
3945	8.2	

Plate VI - ContinuedCurve V (continued)

3995	8.4	
4035	8.6	
4080	8.8	
4120	9.0	
4140	9.2	
4200	9.4	-190
4230	9.6	
4260	9.8	
4320	10.0	
4340	10.2	
4385	10.6	
4420	11.1	
4455	11.3	-192
4500	11.4	
4530	11.8	
4585	12.2	
4620	12.6	-190
4656	13.3	
4680	13.6	
4710	14.2	
4775	15.0	
4830	15.8	
4868	16.4	
4915	17.2	
4945	18.1	
4995	19.3	
5040	20.2	
5080	21.7	
5120	23.2	
5175	25.4	
5225	27.7	
5280	30.6	
5340	33.1	
5400	43.6	
5475	104.7	-190

Curve VI

100 c.c. Na_2SiO_3
 150 c.c. HAc
 20 c.c. H_2O

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
60	414	-180
945	4.6	
945	4.8	
1200	4.9	
2190	5.2	-182
2345	5.6	
2380	5.8	
2385	6.0	

Plate VI - ContinuedCurve VI - (continued)

3272	8.2	
3330	8.8	
3710	7.0	
3770	7.2	-182
3800	7.4	
3950	7.6	
4000	7.8	
4075	8.1	
4170	8.2	
4215	8.4	
4280	8.6	
4295	8.8	-182
4330	8.9	
4410	9.3	
4505	9.3	
4540	9.9	
4580	10.2	
4610	10.3	
4690	10.9	
4790	11.4	
4850	11.8	
4895	12.4	
4935	12.8	
4995	13.6	-182
5080	14.2	
5125	14.9	
5165	15.6	
5220	16.0	
5255	16.6	
5295	17.6	
5340	18.2	
5375	19.0	
5415	19.9	
5480	21.0	
5500	22.3	
5550	23.9	
5580	25.4	
5600	27.4	
5640	29.8	
5690	32.9	
5745	37.4	
5870	43.5	
5940	53.6	-182

Table VI - ContinuedCurve VII

100 c.c. Na_2SiO_3
180 c.c. HAc

Viscometer 2

<u>Time after mix (sec.)</u>	<u>Time of flow (sec.)</u>	<u>Potentiometer</u>
90	4.2	-175
330	4.4	-177
2730	5.0	
5425	5.2	-180
3500	5.4	
4380	6.0	-180
5290	7.2	
5400	7.6	
5480	7.8	
5580	8.2	
5850	8.8	
5990	9.4	
6270	10.4	
6330	10.8	
6460	11.8	
6570	12.4	
6692	13.5	
6780	14.0	
6840	14.9	
6885	15.2	
6985	16.2	
7000	16.8	-181
7080	17.8	
7130	18.8	
7175	19.5	
7215	20.2	
7280	21.3	
7300	21.8	-181
7350	23.0	
7400	24.8	
7465	26.2	
7505	28.2	
7535	30.3	
7620	33.1	
7675	36.2	
7740	42.2	
7815	55.2	
7920	143.2	-181

SUMMARY

1. Viscosity curves obtained by the use of various acid in differing concentrations have been obtained.
2. Micro photographs of etch patterns of gels have been obtained.
3. A structure of silica gels has been advanced.
4. The applicability of the Ostwald viscometer in the following of gelation has been attacked.

BIBLIOGRAPHY

1. Krulyt - Colloids
2. Flemming - Z. Physik. Chem. 41, 427 (1902)
3. Hurd and Carver - J. Phys. Chem. 37, 321 (1933)
4. Hurd and Hallstrom - Senior Thesis
5. Prasad, Mehta and Desai - J. Phys. Chem. 36, 1394 (1932)
6. Hurd and Santora - Senior Thesis
7. Hurd and Fraser - Senior Thesis
8. Dahr and Chakravarty - Kolloid Z. 44, 225 (1928)
9. Bogue - Colloidal Behavior
10. Zsigmondy - Z. Anorg. Chem. 71, 353 (1911)
11. Bachmann - Z. Anorg. Chem. 73, 125 (1912)
12. Bachmann - Zeit. Kolloidchemie, 11, 145 (1912)
13. Hurd and Griffith - J. Phys. Chem. 39, 1159 (1935)
14. Daniels, Mathews, and Williams - Experimental Physical Chemistry
15. Hurd and Letteron - Senior Thesis
16. Hurd - Some New Experiments on Silicic Acid Gels - J. Chem. Ed.,
Vol. 14, No. 2 (1937)
17. Housink - Elasticity, Plasticity and the Structure of Matter
18. Hurd - Theories for the Mechanism of the Setting of Silicic Acid Gels -
Chem. Rev., Vol. 22, No. 3 (1938)
19. Batschli - Untersuchungen uber Strukturen, Leipzig (1898)
20. Holmes - Laboratory Manual of Colloid Chemistry