

2 MAY 18 1956 REC'D

1956

00271

(1)

N-39662  
Part I

WADC TECHNICAL REPORT 55-290

AD-A279 285



# THE DEVELOPMENT OF FIBROUS GLASSES HAVING HIGH ELASTIC MODULI

GEORGE R. MACHLAN

OWENS-CORNING FIBERGLAS CORPORATION  
NEWARK, OHIO



NOVEMBER 1955

LIBRARY COPY

MAY 31 1956

LEI [REDACTED]

This document has been approved  
for public release and sale; its  
distribution is unlimited

DTIC QUALITY INSPECTED 1

1138 94-13792

WRIGHT AIR DEVELOPMENT CENTER

94 8 00 019

## NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

- - - - -

Qualified requesters may obtain copies of this report from the ASTIA Document Service Center, Knott Building, Dayton 2, Ohio.

- - - - -

This report has been released to the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., for sale to the general public.

- - - - -

Copies of WADC Technical Reports and Technical Notes should not be returned to the Wright Air Development Center unless return is required by security considerations, contractual obligations, or notice on a specific document.

# THE DEVELOPMENT OF FIBROUS GLASSES HAVING HIGH ELASTIC MODULI

GEORGE R. MACHLAN

OWENS-CORNING FIBERGLAS CORPORATION  
NEWARK, OHIO

NOVEMBER 1955

MATERIALS LABORATORY  
CONTRACT No. AF 33(616)-2422  
PROJECT No. 7340  
TASK No. 73400

WRIGHT AIR DEVELOPMENT CENTER  
AIR RESEARCH AND DEVELOPMENT COMMAND  
UNITED STATES AIR FORCE  
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

|                    |                      |
|--------------------|----------------------|
| Accession For      |                      |
| NTIS               | CRA&I                |
| DTIC               | TAB                  |
| Unannounced        |                      |
| Justification      |                      |
| By                 |                      |
| Distribution /     |                      |
| Availability Codes |                      |
| Dist               | Avail and/or Special |
| A-1                |                      |

## FOREWORD

This report was prepared by Dr. George R. Machlan of the Research Laboratories, Owens-Corning Fiberglas Corporation, Newark, Ohio under USAF Contract No. AF 33(616)-2422. This contract was initiated under Project No. 7340, "Rubber, Plastic and Composite Materials", Task No. 73400, "Structural Plastics", formerly RDO No. 614-12, "Structural Plastics", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt. A.E. Morse acting as project engineer.

This report covers the period of work from June 1954 to July 1955.

The services of Mr. F. W. Glaze, the National Bureau of Standards, Dr. F. V. Tooley, University of Illinois, Dr. F. W. Preston, Preston Laboratories, and Dr. N. J. Kreidl, Bausch & Lomb Optical Company, for consultation on this investigation are gratefully acknowledged.

## ABSTRACT

A fifty percent increase in modulus of elasticity of fibrous glass was achieved by the continuous formation of fibers of a calcium aluminate glass in a small textile glass bushing.

The resistance of these glasses to chemical attack by water and water vapor is much less than that of commercially produced textile fibrous glass. The glasses are resistant to hydrofluoric acid but are completely soluble in hydrochloric acid.

The dielectric constants of these glasses were found to be higher than the dielectric constant of present textile glass and the loss tangents were found to be approximately the same as that of present textile glass.

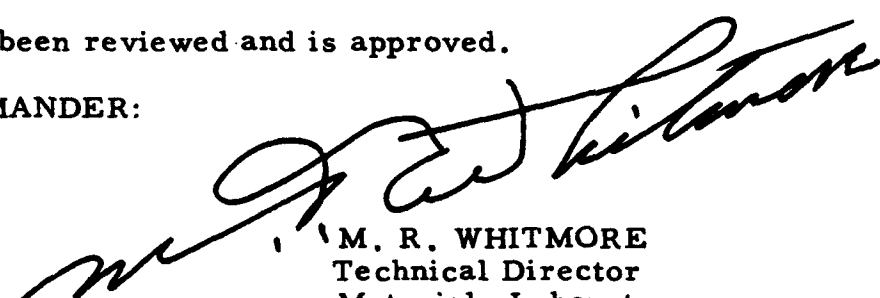
Several compositions were investigated which contained tin oxide as the major constituent but no glasses were found.

An exploratory study of glass-plastic combinations from the calcium aluminate glass was initiated. Volan A was found to be the best coupling agent tested for this glass.

## PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:



M. R. WHITMORE  
Technical Director  
Materials Laboratory  
Directorate of Research

# TABLE OF CONTENTS

|                                                                                                         | <u>Page</u> |
|---------------------------------------------------------------------------------------------------------|-------------|
| I. Introduction.....                                                                                    | 1           |
| II. Materials, Testing Procedures, and Equipment.....                                                   | 3           |
| III. Compositional Studies.....                                                                         | 5           |
| a. Phase I. Work Prior to Contract.....                                                                 | 5           |
| b. Phase II Work Since June 1954.....                                                                   | 8           |
| IV. Fiber Formation Studies.....                                                                        | 72          |
| V. Glass-Plastic Combination Studies.....                                                               | 74          |
| VI. General Conclusions and Summary.....                                                                | 76          |
| VII. Recommendations.....                                                                               | 77          |
| VIII. Bibliography.....                                                                                 | 78          |
| Appendix I, Hot Stage Microscope.....                                                                   | 79          |
| Appendix II, Determination of the Viscosity of<br>Glass Melts with the Brookfield<br>Viscometer.....    | 81          |
| Appendix III, Determination of the Liquidus<br>Temperature by the Gradient Method.....                  | 84          |
| Appendix IV, The Surface Tension of Glasses<br>Determined by the Maximum<br>Bubble Pressure Method..... | 87          |
| Appendix V, Measurement of Young's Modulus.....                                                         | 90          |
| Appendix VI, Fiber Forming Apparatus.....                                                               | 98          |
| Appendix VII, Single Fiber Tensile Tests.....                                                           | 101         |
| Appendix VIII, The Formation of Glass-Plastic<br>Test Samples.....                                      | 104         |

## LIST OF TABLES

| Table |                                                                       | Page |
|-------|-----------------------------------------------------------------------|------|
| I     | Exploratory Calcium Aluminate Glasses .....                           | 9    |
| II    | Physical Properties of Exploratory<br>Calcium Aluminate Glasses ..... | 41   |
| III   | Systematic Study of Calcium Aluminate Glasses .....                   | 44   |
| IV    | Physical Properties of Calcium Aluminate Glasses .....                | 59   |
| V     | Physical Properties of Glass-Plastic<br>Combinations .....            | 75   |

# LIST OF ILLUSTRATIONS

| Figure |                                                                     | Page |
|--------|---------------------------------------------------------------------|------|
| 1.     | Area of Glass Formation .....                                       | 68   |
| 2.     | Young's Moduli of Annealed Glasses .....                            | 69   |
| 3.     | Liquidus Temperatures.....                                          | 70   |
| 4.     | Viscosity of Melt.....                                              | 71   |
| 5.     | Hot Stage Microscope.....                                           | 80   |
| 6.     | Brookfield Viscometer Furnace and Control.....                      | 82   |
| 7.     | Brookfield Viscometer.....                                          | 83   |
| 8.     | Gradient Liquidus Furnaces.....                                     | 85   |
| 9.     | Liquidus Boats.....                                                 | 86   |
| 10.    | Surface Tension Apparatus.....                                      | 88   |
| 11.    | Crucible and Capillary Tube for Surface Tension<br>Measurement..... | 89   |
| 12.    | Young's Modulus Apparatus for Bulk Samples.....                     | 94   |
| 13.    | Sample Mounting for Young's Modulus Measurement.....                | 95   |
| 14.    | Young's Modulus Apparatus for Fiber Samples.....                    | 96   |
| 15.    | Fiber Sample Mounting for Young's Modulus<br>Measurement.....       | 97   |
| 16.    | One Hole Bushing Apparatus.....                                     | 99   |
| 17.    | One Hole Bushing.....                                               | 100  |
| 18.    | Tensile Strength Measurement.....                                   | 102  |
| 19.    | Sample Mounting for Tensile Strength<br>Measurement.....            | 103  |
| 20.    | Preparation of Glass-Plastic Rod Samples.....                       | 105  |

## I. INTRODUCTION

High modulus fibrous glass was required primarily for reinforced plastic materials. Modulus of present fibrous "E" glass is approximately  $10.5 \times 10^6$  psi and yields a reinforced plastic having a modulus of approximately  $3 \times 10^6$  psi. If the modulus of the glass could be increased to  $20 \times 10^6$  psi, the resulting reinforced plastic might have a modulus of approximately  $5 \times 10^6$  psi or one half that of aluminum metal.

The development of high modulus silicate glasses did not seem feasible since the moduli of these glasses fell in the range  $8 \times 10^6$  psi to  $15 \times 10^6$  psi. The moduli of phosphate and borate glasses were less well known but there was no reason to believe that either of these glassy systems had moduli significantly different than the silicate glasses.

It was thought that a clue to the development of high modulus glasses might be obtained from the study of the moduli of the crystalline oxides. Vitreous silica had a modulus of  $10 \times 10^6$  psi which corresponded very well to the silicate glasses as well as to the crystalline forms of silica. Oxides which had high crystalline moduli and which were possible glass formers were alumina, zirconia, titania and tin oxide. The only known glasses in any of these oxide systems were calcium aluminates. If the modulus of these aluminate glasses corresponded to the modulus of crystalline alumina, extremely high modulus glasses would be obtained. The modulus of crystalline alumina was known to be approximately  $55 \times 10^6$  psi and spinel, a magnesium aluminate, was known to be approximately  $30 \times 10^6$  psi. The formation of glass in the aluminate system with calcium oxide was also fortunate, since calcium oxide was known to increase the modulus of silicate glasses more than any other oxide.

Morey (1) reports that the addition of calcium oxide into silicate glasses gave the greatest increase in Young's modulus when substituted on a weight percent basis for silicon dioxide. Aluminum oxide did not increase the modulus of silicate glasses as much as would have been anticipated from the modulus of the crystalline alumina. The lower modulus of the alumina in the silicate glass was probably because the alumina entered the silica network in four-fold coordination rather than six-fold coordination as in corundum. The moduli of elasticity of the early calcium aluminate glasses were substantially greater than in the corresponding silicate glasses but the alumina was obviously present in four-fold coordination as in the silicate glass. This conclusion was in agreement with Zachariasen's (2) original requirement for glass formation, i.e., that the glass former must have a low coordination number.

It was further thought that the other high modulus oxides, titania, zirconia and tin oxide could be considered as modifying constituents to the calcium aluminate glasses or as possible glass formers in their own systems. Other oxides, such as the alkali metal oxides, the alkaline earth oxides were to be used as modifiers to obtain the properties desired for fiber formation. The oxides of zinc, copper, iron and manganese were to be investigated as possible modifiers to lower liquidus temperatures and to improve the chemical durability.

An investigation to develop a high elastic modulus glass for fibers was initiated at Owens-Corning Fiberglas Corporation in July, 1953, before the initiation of this contract. The investigation began with the development of glasses in the calcium aluminate system. This system was chosen because it was believed that the high modulus of calcium oxide and aluminum oxide would transfer into the glassy system.

Dr. F. W. Glaze of the National Bureau of Standards, at the 1953 Fall Meeting of the Glass Section of the American Ceramic Society at Rochester, New York, presented their work on calcium aluminate glasses for infrared transmission. In this work, Young's modulus was found to be higher for these glasses than the corresponding silicate glass.

The addition of oxides other than calcium and aluminum were made to obtain the necessary high temperature physical properties required for fiber formation. The calcium aluminate glasses in general have high liquidus temperatures, are extremely fluid melts, and have rapid rates of devitrification during cooling. These characteristics made fiberization of nearly all these glasses difficult by the continuous filament process. Only by the addition of small quantities of other oxides to lower the liquidus temperature and increase the viscosity of the melt was fiberization possible.

The addition of oxides, other than those of calcium and aluminum, also affected the modulus of elasticity of the resulting glass.

The alkali oxides normally lower temperatures, decrease the viscosity and decrease Young's modulus. These oxides were used in the compositions to decrease the liquidus temperature of the melt. The alkaline earth oxides cannot be characterized in the same way as the alkali metal oxides. The changes in viscosity, liquidus temperature and Young's modulus in the substitution of these oxides in a glass was dependent on the initial composition and how the substitution was made.

Titanium dioxide and zirconium dioxide were used in the early composition work because it was believed these oxides would increase the modulus of the resulting glass. This belief was based on the high moduli of their respective crystalline oxides. Titanium dioxide tended to lower liquidus temperatures and to decrease the viscosity of the melt. Zirconium dioxide tended to raise the liquidus temperature and to increase the viscosity of the melt.

Silicon dioxide and boron oxide were added to the calcium aluminate compositions to lower the liquidus temperatures and increase the viscosity of the melt. These oxides lowered Young's modulus of the resulting glass.

Physical properties other than elastic modulus had to be considered as part of this investigation because of the demands of fiber formation and the applications of the glass fibers formed. The physical property requirements for a glass to be considered for the production of high modulus glass fibers were as follows:

1. The melt had to be viscous enough above the liquidus temperature that the fibers could be formed continuously from the melt.
2. The glass had to have a liquidus temperature low enough that it could be melted and worked in platinum bushings.
3. The chemical durability of the finished fiber had to be comparable to that of present commercial fibrous glass.
4. The finished glass fiber had to have a strength comparable to that of present commercial fibrous glass.

## II. MATERIALS, TESTING PROCEDURES AND EQUIPMENT

The batch materials used in the compositions reported were as follows:

No. 6 limestone flour from National Gypsum of Bellefonte, Pa. was the source of calcium oxide.

C-31, hydrated alumina from Aluminum Company of America was the source of aluminum oxide.

Novacite from Malvern Minerals of Hot Springs, Arkansas was the source of silicon dioxide.

All other materials used were of technical grade or better.

The sodium oxide was added as technical grade sodium nitrate. The barium oxide, potassium oxide and lithium oxide were added as their respective carbonates.

All compositions are recorded as calculated to the batch and do not necessarily represent the exact composition of the finished glass. No chemical analyses were made of the glasses.

All melting of the compositions was done by one of the following methods:

1. Small exploratory bead melts were made on a platinum strip heated electrically.
2. Small ten to twenty gram batches were melted in platinum crucibles in a platinum wound electric furnace.
3. Large batches of one thousand grams or more were melted in a gas fired Remmey muffle furnace.

The first method mentioned above was the hot stage for the hot stage microscope. This melting procedure and apparatus is described in Appendix I, page 79.

Viscosity measurements on the glasses were made using the Brookfield viscometer as described in Appendix II, page 81.

Liquidus temperatures were determined on the hot stage microscope and by the gradient method as described in Appendix III, page 84.

The surface tension of a few glasses was determined by the maximum bubble pressure method as described in Appendix IV, page 87.

Young's moduli were determined for both bulk samples and fiber samples by the sonic method as described in Appendix V, page 90.

The fiber forming was done from a platinum bushing as described in Appendix VI, page 98.

Tensile strength of a few fibers were determined with the apparatus described in Appendix VII, page 101.

Glass-plastic combination rod samples were prepared for testing as described in Appendix VIII, page 104.

### III. COMPOSITIONAL STUDIES

#### a. Phase I. Work Prior to Contract

The first phase of this investigation was to determine in an exploratory manner the extent of glass formation in the calcium aluminate system, the moduli of elasticity of these glasses and if properties compatible with fiber formation could be obtained.

The compositions studied in the first phase are listed with their respective melting temperatures and liquidus temperatures in Table I. (pg.9 ). The melting and liquidus temperatures shown in Table I are not precise, since they were obtained from examination of the melts on a hot stage microscope, Appendix I, (pg.79 ), and only comparative values could be obtained. The liquidus temperatures, in particular, are subject to large errors, since they were dependent upon the rate of crystallization of the melt and the rate at which the temperature of the stage was changed. All compositions in Table I up to No. 146 are expressed in mole percent. All those beyond No. 146 are expressed in cation percent after Sun. (4). Mole percent, means that each of the oxides was expressed in its usual stoichiometric manner; for example,  $\text{Na}_2\text{O}$  for sodium oxide,  $\text{CaO}$  for calcium oxide,  $\text{Al}_2\text{O}_3$  for aluminum oxide. Cation percent means that each of the oxides was expressed with unit cation; for example,  $\text{NaO}_{0.5}$  for sodium oxide,  $\text{CaO}$  for calcium oxide,  $\text{AlO}_{1.5}$  for aluminum oxide.

In Table I, page 9 , the liquidus temperatures and melting temperatures were determined on the hot stage microscope. (Appendix I.). The letter "g" beside the melting temperature signifies that glass was formed when melt was quenched rapidly on the hot stage. The letter "d" signifies that the composition melted at the temperature shown but devitrified on quenching. The letter "pd" indicates melting but partial devitrification on cooling and the letter "s" indicates that the composition did not melt at the temperature shown. An asterisk (\*) after the letter "g" indicates that devitrification did occur in melts larger than those used on the hot stage.

The best glass in a series was determined from the melting temperature and liquidus temperature as observed and the appearance of devitrification in the glass when produced in melts of ten grams or more.

Compositions Nos. 1 - 4 were the initial compositions melted in this series and were in the three component system  $2 \text{CaO} \cdot \text{SiO}_2 - \text{CaO} - \text{Na}_2\text{O} \cdot 6 \text{Al}_2\text{O}_3$ . All these compositions melted at  $2900^\circ\text{F}$ . on the hot stage microscope. Glass No. 2 was taken as a base glass because of the absence of silica.

Compositions Nos. 5 - 8 were the initial introductions of  $\text{TiO}_2$  into the compositions. The  $\text{TiO}_2$  was added as  $\text{Na}_2\text{O} \cdot \text{TiO}_2$ . Small additions of  $\text{TiO}_2$  lower the liquidus temperatures but large additions increase the liquidus temperature, decrease the viscosity of the melt and increase the devitrification rate.

Compositions Nos. 9 - 24 and 34 - 47 were in the three component diagram  $\text{CaO} - \text{Na}_2\text{O} \cdot 6 \text{Al}_2\text{O}_3 - \text{Na}_2\text{O} \cdot \text{TiO}_2$ . The lowest liquidus temperatures were found in the glasses containing 5%  $\text{Na}_2\text{O} \cdot \text{TiO}_2$  and 40 - 50%  $\text{Na}_2\text{O} \cdot 6 \text{Al}_2\text{O}_3$ . These glasses are Nos. 9, 38 and 39.

Compositions Nos. 25 - 37 and Nos. 48 - 59 were in the three component field  $\text{CaO} - \text{Na}_2\text{O} \cdot 6 \text{Al}_2\text{O}_3 - \text{TiO}_2$ . The lowest liquidus glasses containing  $\text{TiO}_2$  were on the 5%  $\text{TiO}_2$  level and 40 - 50%  $\text{Na}_2\text{O} \cdot 6 \text{Al}_2\text{O}_3$ .

Compositions Nos. 60 - 80 were systematic substitutions of  $\text{MgO}$  and  $\text{BaO}$  for  $\text{CaO}$ .

Compositions Nos. 81 - 103 were a systematic substitution of the  $\text{Li}_2\text{O}$  and  $\text{K}_2\text{O}$  for  $\text{Na}_2\text{O}$  in Glass No. 67. The optimum ratio of  $\text{Na}_2\text{O}:\text{Li}_2\text{O}:\text{K}_2\text{O}$  was found to be 5:4:1 found in No. 90.

Compositions Nos. 104 - 113 were a systematic substitution of  $\text{ZrO}_2$  for  $\text{CaO}$  in No. 67. The addition of  $\text{ZrO}_2$  up to 25% of the total  $\text{CaO}$  could be accomplished. At 25% the melting temperature was approaching the limit of the maximum available temperature of the hot stage microscope. A definite phase separation was noted in these glasses when melted in large amounts in platinum crucibles.

Compositions Nos. 114 - 123 were a systematic substitution of  $\text{ZnO}$  for  $\text{CaO}$ . This substitution did lower the apparent melting temperature and liquidus temperature. Large melts, however, could not be produced without excessive devitrification.

Compositions Nos. 127 - 134 were a continuation of the substitution of  $\text{ZrO}_2$  for  $\text{CaO}$  from 25% to 50% of the total  $\text{CaO}$ . The melting temperature went above the temperature available on the hot stage after about 30% of the total  $\text{CaO}$  had been substituted.

Compositions Nos. 135 - 138 were substitutions of  $\text{CuO}$  and  $\text{Cu}_2\text{O}$  for  $\text{Na}_2\text{O}$  in No. 134. All of these compositions devitrified while cooling on the hot stage.

Compositions Nos. 139 - 145 were random substitutions of  $\text{ZnO}$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{SiO}_2$  into these compositions. Composition No. 134 did not melt to a clear glass at  $2950^\circ\text{F}$ . Compositions Nos. 140 - 144 melted to clear glasses on the hot stage of the microscope, but devitrified when melted in large quantities. Composition No. 145 did not melt at  $2900^\circ\text{F}$ .

Composition No. 146 marks the initiation of cation substitution rather than molar substitution.

From Compositions Nos. 146 to 367, random substitutions of all components and additions of  $\text{FeO}_{1.5}$ ,  $\text{SiO}_2$ ,  $\text{MnO}_2$ ,  $\text{MnO}$  were studied. The best compositions found in this random study were Nos. 166, 197, 211, 310, 313, 314, 336 and 339.

Compositions Nos. 368 - 394 were a systematic substitution of  $\text{MgO}$  and  $\text{BaO}$  for  $\text{CaO}$  in Glass No. 313. The best glass found in this substitution was No. 386.

Compositions Nos. 395 - 426 were a systematic study of the substitution of  $\text{TiO}_2$  and  $\text{ZrO}_2$  for  $\text{AlO}_{1.5}$  in Ca 386. Glasses in which more than 5% of the total acidic components ( $\text{AlO}_{1.5} + \text{TiO}_2 + \text{ZrO}_2$ ) was either  $\text{TiO}_2$  or  $\text{ZrO}_2$  did not melt into glasses at  $2750^\circ\text{F}$ . or devitrified on cooling.

Compositions Nos. 427 - 444 were a systematic variation of the total alkali, alkaline earth and acid components based on the ratio of each group as found in No. 402. In this study all compositions containing more than 17.5% total alkali and more than 57.5% total acidic components did not melt to clear glasses. The best glass found in this study was No. 432.

Compositions Nos. 445 - 463 were a systematic study of the substitution of  $\text{K}_2\text{O}$  and  $\text{Li}_2\text{O}$  for  $\text{Na}_2\text{O}$  in Glass No. 432. Glasses were formed throughout the entire substitution. Compositions Nos. 461, 462 and 463 could not be melted to clear glasses in small crucibles containing ten gram melts. Glass No. 451 was the best glass in this group.

Compositions Nos. 464 - 483 were a systematic substitution of  $\text{BO}_{1.5}$  and  $\text{SiO}_2$  for  $\text{AlO}_{1.5}$ . Compositions Nos. 481 - 483 were never melted because several good glasses were found without going beyond 6% of the total acidic oxide content with  $\text{BO}_{1.5}$ . The properties of these glasses became better as the substitution of  $\text{SiO}_2$  for  $\text{Al}_2\text{O}_3$  increased.

Compositions Nos. 484 - 501 were a systematic substitution of  $\text{MgO}$  and  $\text{BaO}$  for  $\text{CaO}$  in Glass No. 451. The best glass found in this group was No. 492.

Compositions Nos. 502 - 514 were a continuation of the substitution of  $\text{SiO}_2$  and  $\text{BO}_{1.5}$  for  $\text{AlO}_{1.5}$  started in Nos. 464 - 483. The glass properties continued to improve as  $\text{SiO}_2$  was substituted for  $\text{AlO}_{1.5}$ . Glasses 505 B, 506 B, 507 B, 508 B, 509 B were produced later in the investigation to determine the effect of the  $\text{BeO}$  substitution for  $\text{CaO}$  in these compositions.

Compositions Nos. 515 - 531 and Nos. 552 - 561 were a study of the systematic substitution of  $\text{ZnO}$  and  $\text{PbO}$  for  $\text{CaO}$  in glass No. 508. All compositions devitrified on cooling. The letters "dm" after the melting temperature in this group indicates the presence of reduced metal in these melts. All melts in this group were made in refractory crucibles rather than platinum.

Compositions Nos. 532 - 551 were a study of the systematic substitution of  $ZrO_2$  and  $TiO_2$  for  $AlO_{1.5}$  and one half the  $CaO$  was added as  $CaF_2$  to lower the melting and liquidus temperature.

Compositions Nos. 552 - 591 were high  $ZnO$  containing compositions. None of these compositions fused at  $2900^\circ F$ .

Compositions Nos. 592 - 631 were a variation of the alkali, alkaline earth and acidic groups in the proportions found in Composition No. 581. None of these compositions melted at  $2900^\circ F$ .

Table II, page 41, contains the results of Young's moduli measurements, viscosity and density measurements for the best glasses found in this early part of the investigation. The moduli and density values reported in Table II are all for annealed glass. The highest modulus glass found in this early investigation is No. 197 which had a modulus at  $16.7 \times 10^6$  psi and the lowest modulus glass found in this group was No. 508 which had a modulus of  $15.42 \times 10^6$  psi. The density of all the glasses in this series fell in the range of 2.8 to 3.2 gms/ml. Table II indicates the viscosity of the melt by recording the temperature at which the logarithm of the viscosity, in poises, was 0.5, 1.0, 1.5 and 2.

Viscosity measurements were generally limited to temperatures below  $2750^\circ F$ . and to temperatures above the liquidus temperature of the glass or the point at which the melt devitrified in the measuring apparatus. The most viscous glass shown in Table II, therefore, is No. 395, and the most fluid glass shown in Table II is No. 166. All viscosity measurements reported in Table II were made using the Brookfield Viscometer as described in Appendix I.

The formation of fibers in the standard one hole bushing was attempted on all glasses listed in Table II. Small quantities of fiber could be formed on Nos. 492, 506, 508 and 511. The best of these was No. 508. Attempts to fiberize all of the other glasses resulted in either the glass being too fluid to form fibers or in devitrification of the glass in the bushing tips. A more detailed discussion of the formation of fibers of these glasses will be given in a later section of this report.

#### b. Phase II. Work Since June 1954

The next phase of the investigation was a systematic study of variations of the constituents to obtain the highest possible modulus with the best viscosity liquidus temperature relationship for fiber formation. The compositions studied in this phase are shown in Table III, page 44.

TABLE I.  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | Na <sub>2</sub> O | Al <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | SiO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------------------|--------------------------------|------------------|------------------|----------------------|-----------------------|
| 1                  | 41.48 | 7.48              | 44.73                          |                  | 6.31             | 2900 g               | 2700                  |
| 2                  | 53.37 | 6.64              | 40.00                          |                  |                  | 2950 g               | 2600                  |
| 3                  | 50.42 | 6.48              | 38.76                          |                  | 4.34             | 2750 g               | 2600                  |
| 4                  | 43.09 | 7.47              | 44.68                          |                  | 4.75             | 2800 g               | 2600                  |
| 5                  | 35.46 | 12.80             | 46.72                          | 5.02             |                  | 2900 d               | 2600                  |
| 6                  | 39.36 | 12.30             | 43.32                          | 5.02             |                  | 2900 d               | 2550                  |
| 7                  | 29.40 | 13.69             | 51.84                          | 5.05             |                  | 2900 d               | 2800                  |
| 8                  | 31.13 | 17.61             | 41.22                          | 10.03            |                  | 2850 pd              | 2700                  |
| 9                  | 50.00 | 10.7              | 34.3                           | 5.3              |                  | 2680 pd              | 2175                  |
| 10                 | 40.00 | 15.7              | 34.30                          | 10.00            |                  | 2850 g               | 2700                  |
| 11                 | 28.00 | 21.00             | 36.00                          | 15.00            |                  | 3000 g               | 2540                  |
| 12                 | 20.00 | 22.10             | 42.90                          | 15.00            |                  | 2900 d               | 2450                  |
| 13                 | 20.00 | 18.60             | 51.40                          | 10.00            |                  | 2800 d               | 2550                  |
| 14                 | 20.00 | 15.00             | 60.00                          | 5.00             |                  | 2900 d               | 2700                  |
| 15                 | 24.00 | 25.10             | 30.90                          | 20.00            |                  | 2950 d               | 2550                  |
| 16                 | 30.00 | 24.30             | 25.70                          | 20.00            |                  | 2950 d               | 2850                  |
| 17                 | 40.00 | 22.90             | 17.10                          | 20.00            |                  | 2950 s               | --                    |
| 18                 | 40.00 | 19.30             | 25.70                          | 15.00            |                  | 2950 s               | --                    |
| 19                 | 40.00 | 26.40             | 8.60                           | 25.00            |                  | 2450 d               | --                    |
| 20                 | 30.00 | 27.90             | 17.10                          | 25.00            |                  | 2950 s               | --                    |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | Na <sub>2</sub> O | Al <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------------------|--------------------------------|------------------|----------------------|-----------------------|
| 21                 | 20.00 | 29.30             | 25.70                          | 25.00            | 2930 d               | 2620                  |
| 22                 | 10.00 | 30.70             | 34.30                          | 25.00            | 2900 d               | 2650                  |
| 23                 | 10.00 | 27.10             | 42.90                          | 20.00            | 2900 s               | --                    |
| 24                 | 10.00 | 23.60             | 51.40                          | 15.00            | 2770 g               | 2500                  |
| 25                 | 51.50 | 6.20              | 38.50                          | 10.00            | 2800 g               | 2600                  |
| 26                 | 55.00 | 5.80              | 35.00                          | 10.00            | 2770 g               | 2500                  |
| 27                 | 45.00 | 7.50              | 45.00                          | 10.00            | 2800 g               | 2600                  |
| 28                 | 48.50 | 6.10              | 36.50                          | 15.00            | 3000 s               | --                    |
| 29                 | 55.00 | 5.00              | 30.00                          | 15.00            | 2800 d               | 2600                  |
| 30                 | 45.00 | 6.70              | 40.00                          | 15.00            | 2950 s               | --                    |
| 31                 | 46.00 | 5.70              | 34.00                          | 15.00            | 2950 s               | --                    |
| 32                 | 50.00 | 5.00              | 30.00                          | 20.00            | 2950 s               | --                    |
| 33                 | 40.00 | 6.70              | 40.00                          | 20.00            | 2950 s               | --                    |
| 34                 | 46.20 | 7.70              | 46.20                          | --               | 2900 d               | 2200                  |
| 35                 | 41.20 | 8.40              | 50.40                          | --               | 2950 pd              | 2550                  |
| 36                 | 36.40 | 9.10              | 54.50                          | --               | 2950 s               | --                    |
| 37                 | 31.60 | 9.70              | 58.70                          | --               | 2950 s               | --                    |
| 38                 | 44.40 | 11.10             | 40.00                          | 4.40             | 2870 g               | 2300                  |
| 39                 | 39.70 | 11.70             | 44.10                          | 4.40             | 2920 g               | 2350                  |
| 40                 | 35.00 | 12.40             | 48.20                          | 4.40             | 2900 d               | 2500                  |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | Na <sub>2</sub> O | Al <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | MgO  | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------------------|--------------------------------|------------------|------|----------------------|-----------------------|
| 41                 | 30.40 | 13.00             | 52.20                          | 4.30             |      | 2950 s               | --                    |
| 42                 | 25.90 | 13.60             | 56.10                          | 4.30             |      | 2950 s               | --                    |
| 43                 | 25.00 | 16.70             | 50.00                          | 8.30             |      | 2970 d               | 2670                  |
| 44                 | 29.40 | 16.10             | 46.10                          | 8.40             |      | 2920 d               | 2700                  |
| 45                 | 33.80 | 15.50             | 42.30                          | 8.50             |      | 2900 pd              | 2670                  |
| 46                 | 27.90 | 17.90             | 43.50                          | 10.70            |      | 2950 pd              | 2670                  |
| 47                 | 23.40 | 22.10             | 39.00                          | 15.60            |      | 2850 pd              | 2500                  |
| 48                 | 46.50 | 7.00              | 41.80                          | 4.70             |      | 2850 g               | 2375                  |
| 49                 | 41.60 | 7.70              | 46.20                          | 4.60             |      | 2800 g               | 2400                  |
| 50                 | 36.60 | 8.40              | 50.40                          | 4.60             |      | -- s                 | --                    |
| 51                 | 31.80 | 9.10              | 54.50                          | 4.50             |      | -- s                 | --                    |
| 52                 | 36.90 | 7.70              | 46.20                          | 9.20             |      | 2850 d               | 2650                  |
| 53                 | 32.10 | 8.40              | 50.40                          | 9.20             |      | 2950 d               | 2780                  |
| 54                 | 27.30 | 9.10              | 54.50                          | 9.10             |      | 2950 s               | --                    |
| 55                 | 27.50 | 8.40              | 50.40                          | 13.70            |      | 2920 d               | 2550                  |
| 56                 | 32.30 | 7.70              | 46.20                          | 13.80            |      | 2920 d               | 2650                  |
| 57                 | 37.20 | 7.00              | 41.80                          | 14.00            |      | 2950 s               | --                    |
| 58                 | 32.60 | 7.00              | 41.80                          | 18.60            |      | 2940 d               | 2800                  |
| 59                 | 27.70 | 7.00              | 46.20                          | 18.50            |      | 2950 s               | --                    |
| 60                 | 40.21 | 6.41              | 38.49                          | 3.76             | 5.13 | 2770 g               | 2250                  |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | BaO   | Na <sub>2</sub> O | Al <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|-------|-------------------|--------------------------------|------------------|----------------------|-----------------------|
| 61                 | 41.07 | 10.27 |       | 6.41              | 38.49                          | 3.76             | 2720 g               | 2150                  |
| 62                 | 35.94 | 15.40 |       | 6.41              | 38.49                          | 3.76             | 2900 s               | --                    |
| 63                 | 30.80 | 20.54 |       | 6.41              | 38.49                          | 3.76             | 2950 s               | --                    |
| 64                 | 25.67 | 25.67 |       | 6.41              | 38.49                          | 3.76             | 2950 s               | --                    |
| 65                 | 20.54 | 30.80 |       | 6.41              | 38.49                          | 3.76             | 2950 s               | --                    |
| 66                 | 46.21 | --    | 5.13  | 6.41              | 38.49                          | 3.75             | 2710 d               | 2420                  |
| 67                 | 41.07 | 5.13  | 5.13  | 6.41              | 38.49                          | 3.76             | 2720 g               | 2175                  |
| 68                 | 35.94 | 10.27 | 5.13  | 6.41              | 38.49                          | 3.76             | 2750 pd              | 2275                  |
| 69                 | 30.80 | 15.40 | 5.13  | 6.41              | 30.49                          | 3.71             | 2950 pd              | 2300                  |
| 70                 | 25.67 | 20.54 | 5.13  | 6.41              | 38.49                          | 3.76             | 2950 s               | --                    |
| 71                 | 20.54 | 25.67 | 5.13  | 6.41              | 38.49                          | 3.76             | 2950 s               | --                    |
| 72                 | 41.07 | --    | 10.27 | 6.41              | 38.49                          | 3.76             | 2930 d               | 2400                  |
| 73                 | 43.64 | 5.13  | 2.57  | 6.41              | 38.49                          | 3.76             | 2620 g               | 2080                  |
| 74                 | 41.07 | 7.70  | 2.57  | 6.41              | 38.49                          | 3.76             | 2700 g               | 2250                  |
| 75                 | 38.80 | 10.27 | 2.57  | 6.41              | 38.49                          | 3.76             | 2720 g               | 2220                  |
| 76                 | 35.94 | 12.84 | 2.57  | 6.41              | 38.49                          | 3.76             | 2910 pd              | 2500                  |
| 77                 | 38.50 | 5.13  | 7.70  | 6.41              | 38.49                          | 3.76             | 2720 pd              | 2120                  |
| 78                 | 35.94 | 7.70  | 7.70  | 6.41              | 38.49                          | 3.76             | 2750 d               | 2300                  |
| 79                 | 33.37 | 10.27 | 7.70  | 6.41              | 38.49                          | 3.76             | 2700 pd              | 2400                  |
| 80                 | 30.80 | 12.84 | 7.70  | 6.41              | 38.49                          | 3.76             | 2950 s               | --                    |

TABLE I. (Cont.)

## EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | Na <sub>2</sub> O | K <sub>2</sub> O | Li <sub>2</sub> O | Al <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|-------------------|------------------|-------------------|--------------------------------|------------------|----------------------|-----------------------|
| 81                 | 41.07 | 5.13 | 5.13 | 5.77              | --               | 0.64              | 38.49                          | 3.76             | 2700 g               | 2100                  |
| 82                 | 41.07 | 5.13 | 5.13 | 5.13              | --               | 1.28              | 38.49                          | 3.76             | 2670 g               | 2100                  |
| 83                 | 41.07 | 5.13 | 5.13 | 4.49              | --               | 1.92              | 38.49                          | 3.76             | 2650 d               | 2350                  |
| 84                 | 41.07 | 5.13 | 5.13 | 3.85              | --               | 2.56              | 38.49                          | 3.76             | 2600 g               | 2100                  |
| 85                 | 41.07 | 5.13 | 5.13 | 3.21              | --               | 3.20              | 38.49                          | 3.76             | 2650 g               | 2100                  |
| 86                 | 41.07 | 5.13 | 5.13 | 5.77              | 0.64             | --                | 38.49                          | 3.76             | 2700 g               | 2260                  |
| 87                 | 41.07 | 5.13 | 5.13 | 5.13              | 0.64             | 0.64              | 38.49                          | 3.76             | 2620 pd              | 2300                  |
| 88                 | 41.07 | 5.13 | 5.13 | 4.49              | 0.64             | 1.28              | 38.49                          | 3.76             | 2640 g               | 2300                  |
| 89                 | 41.07 | 5.13 | 5.13 | 3.85              | 0.64             | 1.92              | 38.49                          | 3.76             | 2600 g               | 2200                  |
| 90                 | 41.07 | 5.13 | 5.13 | 3.21              | 0.64             | 2.56              | 38.49                          | 3.76             | 2600 g               | 2150                  |
| 91                 | 41.07 | 5.13 | 5.13 | 2.56              | 0.64             | 3.21              | 38.49                          | 3.76             | 2600 g               | 2100                  |
| 92                 | 41.07 | 5.13 | 5.13 | 5.13              | 1.28             | --                | 38.49                          | 3.76             | 2600 g               | 2100                  |
| 93                 | 41.07 | 5.13 | 5.13 | 4.49              | 1.28             | 0.64              | 38.49                          | 3.76             | 2620 g               | 2100                  |
| 94                 | 41.07 | 5.13 | 5.13 | 3.85              | 1.28             | 1.28              | 38.49                          | 3.76             | 2600 g               | 2050                  |
| 95                 | 41.07 | 5.13 | 5.13 | 3.21              | 1.28             | 1.92              | 38.49                          | 3.76             | 2570 g               | 2200                  |
| 96                 | 41.07 | 5.13 | 5.13 | 2.56              | 1.28             | 2.56              | 38.49                          | 3.76             | 2600 d               | 2400                  |
| 97                 | 41.07 | 5.13 | 5.13 | 1.92              | 1.28             | 3.21              | 38.49                          | 3.76             | 2700 d               | 2520                  |
| 98                 | 41.07 | 5.13 | 5.13 | 4.49              | 1.92             | --                | 38.49                          | 3.76             | 2750 g               | 2100                  |
| 99                 | 41.07 | 5.13 | 5.13 | 3.85              | 1.92             | 0.64              | 38.49                          | 3.76             | 2750 pd              | 2200                  |
| 100                | 41.07 | 5.13 | 5.13 | 3.21              | 1.92             | 1.28              | 38.49                          | 3.76             | 2650 d               | 2500                  |

TABLE I. (Cont.)

## EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | Na <sub>2</sub> O | K <sub>2</sub> O | Li <sub>2</sub> O | Al <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | ZnO  | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|-------------------|------------------|-------------------|--------------------------------|------------------|------------------|------|----------------------|-----------------------|
| 101                | 41.07 | 5.13 | 5.13 | 3.85              | 2.56             | --                | 38.49                          | 3.76             |                  |      | 2800 pd              | 2520                  |
| 102                | 41.07 | 5.13 | 5.13 | 3.21              | 2.56             | 0.64              | 38.49                          | 3.76             |                  |      | 2660 pd              | 2400                  |
| 103                | 41.07 | 5.13 | 5.13 | 3.21              | 3.21             |                   | 38.49                          | 3.76             |                  |      | 2700 g               | 2100                  |
| 104                | 40.04 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 1.03             |      | 2700 g               | 2400                  |
| 105                | 39.02 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 2.05             |      | 2700 g*              | 2200                  |
| 106                | 37.99 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 3.08             |      | 2700 pd              | 2500                  |
| 107                | 36.96 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 4.11             |      | 2720 g*              | 2440                  |
| 108                | 35.94 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 5.13             |      | 2720 g               | 2420                  |
| 109                | 34.91 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 6.16             |      | not melted           |                       |
| 110                | 33.88 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 7.19             |      | 2750 g               | 2200                  |
| 111                | 32.86 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 8.21             |      | 2800 g*              | 2200                  |
| 112                | 31.83 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 9.24             |      | 2800 g               | 2200                  |
| 113                | 30.80 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             | 10.27            |      | 2850 g*              | 2150                  |
| 114                | 40.04 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             |                  | 1.03 | 2800 pd              | 2400                  |
| 115                | 39.02 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             |                  | 2.05 | 2800 g               | 2300                  |
| 116                | 37.99 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             |                  | 3.08 | 2700 g               | 2200                  |
| 117                | 36.96 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             |                  | 4.11 | 2700 g               | 2300                  |
| 118                | 35.94 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             |                  | 5.13 | 2700 g               | 2220                  |
| 119                | 34.91 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             |                  | 6.16 | 2740 g               | 2200                  |
| 120                | 33.88 | 5.13 | 5.13 | 6.41              |                  |                   | 38.49                          | 3.76             |                  | 7.19 | 2850 pd              | 2500                  |

WADC TR 55-290

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | Na <sub>2</sub> O | Al <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | SiO <sub>2</sub> | ZnO                       | K <sub>2</sub> O                       | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|-------------------|--------------------------------|------------------|------------------|------------------|---------------------------|----------------------------------------|----------------------|-----------------------|
| 121                | 32.86 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             |                  |                  | 8.21                      |                                        | 2700 g               | 2300                  |
| 122                | 31.83 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             |                  |                  | 9.24                      |                                        | 2750 g               | 2200                  |
| 123                | 30.80 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             |                  |                  | 10.27                     |                                        | 2680 g               | 2150                  |
| 124                | 29.78 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 11.29            |                  |                           |                                        | 2850 g               | 2350                  |
| 125                | 28.75 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 12.32            |                  |                           |                                        | 2880 g               | 2350                  |
| 126                | 27.72 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 13.35            |                  |                           |                                        | 2930 pd              | 2400                  |
| 127                | 26.70 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 14.37            |                  |                           |                                        | 2980 s               | --                    |
| 128                | 25.67 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 15.40            |                  |                           |                                        | did not melt         |                       |
| 129                | 24.64 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 16.43            |                  |                           |                                        | did not melt         |                       |
| 130                | 23.62 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 17.45            |                  |                           |                                        | did not melt         |                       |
| 131                | 22.59 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 18.48            |                  |                           |                                        | did not melt         |                       |
| 132                | 21.56 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 19.51            |                  |                           |                                        | did not melt         |                       |
| 133                | 20.53 | 5.13 | 5.13 | 6.41              | 38.49                          | 3.76             | 20.54            |                  |                           |                                        | did not melt         |                       |
| 134                | 34.56 | 5.32 | 3.16 | 6.41              | 38.49                          | 3.76             | 10.27            |                  |                           |                                        | 2900 g               | 2075                  |
| 135                | 34.56 | 4.32 | 2.16 | 5.13              | 38.49                          | 3.76             | 10.27            |                  | Cu <sub>2</sub> O<br>1.28 | CuO<br>2.56                            | 2800 pd              | 2200                  |
| 136                | 34.56 | 4.32 | 2.16 | 4.49              | 38.49                          | 3.76             | 10.27            | 1.92             | 3.84                      |                                        | 2850 pd              | 2400                  |
| 137                | 34.56 | 4.32 | 2.16 | 3.85              | 38.49                          | 3.76             | 10.27            | 2.56             | 5.12                      |                                        | did not melt         |                       |
| 138                | 34.56 | 4.32 | 2.16 | 3.21              | 38.49                          | 3.76             | 10.27            | 3.20             | 6.40                      |                                        | did not melt         |                       |
| 139                | 24.29 | 4.32 | 2.16 | 5.13              | 38.49                          | 3.76             | 10.27            | ZnO<br>10.27     |                           |                                        | 2950 pd              | 2400                  |
| 140                | 33.99 | 4.25 | 2.13 | 6.31              | 37.86                          | 3.7;             | 10.10            |                  | SiO <sub>2</sub><br>1.58  | Fe <sub>2</sub> O <sub>3</sub><br>0.26 | 2750 g               | 2150                  |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | Na <sub>2</sub> O                                                       | Al <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | SiO <sub>2</sub> | Fe <sub>2</sub> O <sub>3</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|-------------------------------------------------------------------------|--------------------------------|------------------|------------------|------------------|--------------------------------|----------------------|-----------------------|
| 141                | 33.52 | 4.19 | 2.10 | 6.22                                                                    | 37.34                          | 3.65             | 9.96             | 2.76             | 0.26                           | 2750 g               | 2250                  |
| 142                | 33.05 | 4.14 | 2.07 | 6.13                                                                    | 36.81                          | 3.60             | 9.82             | 4.12             | 0.26                           | 2850 g               | 2250                  |
| 143                | 32.57 | 4.08 | 2.04 | 6.05                                                                    | 36.29                          | 3.55             | 9.68             | 5.48             | 0.26                           | 2750 g               | 2250                  |
| 144                | 32.11 | 4.02 | 2.01 | 5.96                                                                    | 35.77                          | 3.50             | 9.55             | 6.82             | 0.26                           | 2780 g               | 2100                  |
| 145                | 31.16 | 3.90 | 1.95 | 5.76                                                                    | 34.71                          | 3.40             | 9.26             | 9.79             | 0.05                           | 2800 s               | --                    |
| 146                | 23.66 | 2.98 | 1.49 | <del>Na<sub>2</sub>O 8.85</del><br>Al <sub>2</sub> O <sub>3</sub> 46.05 | 46.05                          | 2.60             | 7.09             | 7.09             |                                | 2750 g               | 2500                  |
| 147                | 27.21 | 2.98 | 1.49 | 8.85                                                                    | 49.59                          | 2.60             | 3.54             | 3.55             |                                | 2600 g               | 2500                  |
| 148                | 23.66 | 2.98 | 1.49 | 8.85                                                                    | 53.14                          | 2.60             | 3.54             | 3.55             |                                | 2650 g               | 2500                  |
| 149                | 23.66 | 4.47 |      | 8.85                                                                    | 53.14                          |                  | 4.84             | 4.85             |                                | 2800 g               | 2500                  |
| 150                | 24.41 | 3.72 |      | 8.85                                                                    | 53.14                          |                  | 4.84             | 4.85             |                                | 2800 g               | 2500                  |
| 151                | 25.15 | 2.98 |      | 8.85                                                                    | 53.14                          |                  | 4.84             | 4.85             |                                | 2800 g               | 2500                  |
| 152                | 25.15 | 2.98 |      | 8.85                                                                    | 55.94                          |                  | 3.54             | 3.55             |                                | 2850 g               | 2550                  |
| 153                | 25.15 | 2.98 |      | 8.85                                                                    | 54.44                          |                  | 4.19             | 4.20             |                                | 2800 g               | 2525                  |
| 154                | 25.15 | 2.98 |      | 8.85                                                                    | 56.54                          |                  | 6.29             |                  |                                | 2850 d               | 2650                  |
| 155                | 25.15 | 2.98 |      | 8.85                                                                    | 58.64                          |                  | 4.19             |                  |                                | 2850 d               | 2650                  |
| 156                | 25.15 | 2.98 |      | 8.85                                                                    | 54.44                          |                  | 8.39             |                  |                                | 2950 s               | --                    |
| 157                | 24.41 | 3.72 |      | 8.85                                                                    | 54.44                          |                  | 8.39             |                  |                                | 2950 s               | --                    |
| 158                | 23.66 | 4.47 |      | 8.85                                                                    | 54.44                          |                  | 8.39             |                  |                                | 2970 s               | --                    |
| 159                | 24.41 | 3.72 |      | 8.85                                                                    | 51.84                          | 2.60             | 8.39             |                  |                                | 2970 d               | 2300                  |
| 160                | 24.41 | 3.72 |      | 8.85                                                                    | 53.14                          | 1.30             | 8.39             |                  |                                | did not melt         |                       |

WADC TR 55-290

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | FeO <sub>1.5</sub> | KO <sub>0.5</sub> | MnO                                | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|--------------------|------------------|------------------|--------------------|-------------------|------------------------------------|----------------------|-----------------------|
| 161                | 24.50 | 4.08 | 4.08 | 9.28               | 55.64              | 2.42             |                  |                    |                   |                                    | 2680 g               | 2000                  |
| 162                | 21.98 | 3.66 | 3.66 | 9.76               | 58.60              | 2.34             |                  |                    |                   |                                    | 2680 d               | 2100                  |
| 163                | 27.42 | 7.09 | 4.57 | 7.98               | 41.90              | 2.52             | 2.52             |                    |                   |                                    | 2680 g               | 2400                  |
| 164                | 24.70 | 6.56 | 4.12 | 8.54               | 51.22              | 2.44             | 2.44             |                    |                   |                                    | 2680 g               | 2150                  |
| 165                | 22.15 | 6.05 | 3.69 | 9.06               | 54.33              | 2.36             | 2.36             |                    |                   |                                    | 2680 g               | 2200                  |
| 166                | 19.75 | 5.58 | 3.29 | 9.54               | 57.25              | 2.29             | 2.29             |                    |                   |                                    | 2680 d               | 2200                  |
| 167                | 27.65 | 9.69 | 4.61 | 7.21               | 43.22              | 2.54             | 5.08             |                    |                   |                                    | 3000 s               | --                    |
| 190                | 21.05 | 3.51 | 3.51 | 4.68               | 52.63              | 7.02             | 5.26             | -                  | 2.34              | -                                  | 2800 g               | 2300                  |
| 191                | 21.05 | 3.51 | 3.51 | 4.68               | 52.63              | 3.51             | 5.26             | -                  | 2.34              | 3.51                               | 2950 g               | 2400                  |
| 192                | 21.05 | 3.51 | 3.51 | 4.68               | 52.63              | 3.51             | 5.26             | 3.51               | 2.34              | -                                  | 2800 g               | 2100                  |
| 193                | 21.05 | 3.51 | 3.51 | 4.68               | 52.63              | 2.34             | 5.26             | 2.34               | 2.34              | 2.34                               | 2800 g               | 2200                  |
| 194                | 21.05 | 3.51 | 3.51 | 4.68               | 52.63              | -                | 5.26             | -                  | 2.34              | 7.02                               | 2800 g               | 2300                  |
| 195                | 21.05 | 3.51 | 3.51 | 4.68               | 52.63              | -                | 5.26             | 3.51               | 2.34              | 3.51                               | 2800 g               | 2200                  |
| 196                | 21.05 | 3.51 | 3.51 | 4.68               | 52.63              | -                | 5.26             | 7.02               | 2.34              | -                                  | 2800 g               | 2150                  |
| 197                | 20.45 | 3.41 | 3.41 | 4.55               | 56.82              | 3.41             | 5.68             | -                  | 2.27              | -                                  | 2850 g               | 2100                  |
| 198                | 20.45 | 3.41 | 3.41 | 4.55               | 56.82              | 1.70             | 5.68             | -                  | 2.27              | 1.70                               | 2950 s               | --                    |
| 199                | 20.45 | 3.41 | 3.41 | 4.55               | 56.82              | 1.70             | 5.68             | 1.70               | 2.27              | -                                  | 2950 g               | 2100                  |
| 200                | 20.45 | 3.41 | 3.41 | 4.55               | 56.82              | 1.14             | 5.68             | 1.14               | 2.27              | <del>MnO<sub>2</sub></del><br>1.14 | 2860 g               | 2300                  |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | AlO <sub>1.5</sub> | KO <sub>0.5</sub> | ZrO <sub>2</sub> | TiO <sub>2</sub> | MnO <sub>2</sub> | FeO <sub>1.5</sub> | Melting Temp. °F. | Liquidus Temp. °F. |
|-----------------|-------|------|------|--------------------|--------------------|-------------------|------------------|------------------|------------------|--------------------|-------------------|--------------------|
| WADC 201        | 20.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | -                | 3.41             | -                  | 2830 g            | 2300               |
| 202             | 20.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | -                | 1.70             | 1.70               | 2900 g            | 2350.              |
| TR 203          | 20.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | -                | -                | 3.41               | 2970 d            | 2550               |
| 55-290 204      | 17.40 | 2.90 | 2.90 | 4.42               | 60.78              | 2.21              | 6.08             | 3.31             | -                | --                 | 2950 s            | --                 |
| 205             | 17.40 | 2.90 | 2.90 | 4.42               | 60.78              | 2.21              | 6.08             | 1.66             | 1.66             | --                 | 2950 s            | --                 |
| 206             | 17.40 | 2.90 | 2.90 | 4.42               | 60.78              | 2.21              | 6.08             | 1.66             | -                | 1.66               | 2950 s            | --                 |
| 207             | 17.40 | 2.90 | 2.90 | 4.42               | 60.78              | 2.21              | 6.08             | 1.11             | 1.11             | 1.11               | 2950 s            | --                 |
| 208             | 17.40 | 2.90 | 2.90 | 4.42               | 60.78              | 2.21              | 6.08             | -                | 3.31             | --                 | 2950 s            | --                 |
| 18 209          | 17.40 | 2.90 | 2.90 | 4.42               | 60.78              | 2.21              | 6.08             | -                | 1.66             | 1.66               | 2950 s            | --                 |
| 210             | 17.40 | 2.90 | 2.90 | 4.42               | 60.78              | 2.21              | 6.08             | -                | -                | 3.31               | 2950 s            | --                 |
| 211             | 17.31 | 2.89 | 2.89 | 8.79               | 54.94              | 4.40              | 5.49             | 3.3-             | -                | --                 | 2750 g            | 2100               |
| 212             | 17.31 | 2.89 | 2.89 | 8.79               | 54.94              | 4.40              | 5.49             | 1.65             | 1.65             | --                 | 2870 g            | 2650               |
| 213             | 17.31 | 2.89 | 2.89 | 8.79               | 54.94              | 4.40              | 5.49             | 1.65             | -                | 1.65               | 2750 g            | 2300               |
| 214             | 17.31 | 2.89 | 2.89 | 8.79               | 54.94              | 4.40              | 5.49             | 1.10             | 1.10             | 1.10               | 2800 g            | 2300               |
| 215             | 17.31 | 2.89 | 2.89 | 8.79               | 54.94              | 4.40              | 5.49             | -                | 3.30             | --                 | 2750 g            | 2300               |
| 216             | 17.31 | 2.89 | 2.89 | 8.79               | 54.94              | 4.40              | 5.49             | -                | 1.65             | 1.65               | 2850 g            | 2350               |
| 217             | 17.31 | 2.89 | 2.89 | 8.79               | 54.94              | 4.40              | 5.49             | -                | -                | 3.30               | 2750 g            | 2350               |
| 218             | 14.44 | 2.41 | 2.41 | 8.55               | 58.83              | 4.28              | 5.88             | 3.21             | -                | --                 | 2950 d            | 2500               |
| 219             | 14.44 | 2.41 | 2.41 | 8.55               | 58.83              | 4.28              | 5.88             | 1.6              | 1.60             | --                 | 2950 s            | --                 |
| 220             | 14.44 | 2.41 | 2.41 | 8.55               | 58.83              | 4.28              | 5.88             | 1.60             | -                | 1.60               | 2950 s            | --                 |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE CLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | AlO <sub>1.5</sub> | KO <sub>0.5</sub> | ZrO <sub>2</sub> | TiO <sub>2</sub> | MnO <sub>2</sub> | FeO <sub>1.5</sub> | Melting<br>Temp. °F | Liquidus<br>Temp. °F |
|--------------------|-------|------|------|--------------------|--------------------|-------------------|------------------|------------------|------------------|--------------------|---------------------|----------------------|
| 221                | 19.44 | 2.41 | 2.41 | 8.55               | 58.83              | 4.28              | 5.88             | 1.07             | 1.07             | 1.07               | 2950 S              | --                   |
| 222                | 14.44 | 2.41 | 2.41 | 8.55               | 58.83              | 4.28              | 5.88             | -                | 3.21             | -                  | 2970 d              | 2300                 |
| 223                | 14.44 | 2.41 | 2.41 | 8.55               | 58.83              | 4.28              | 5.88             | -                | 1.60             | 1.60               | 2950 s              | --                   |
| 224                | 14.44 | 2.41 | 2.41 | 8.55               | 58.83              | 4.28              | 5.88             | -                | -                | 3.21               | 2950 s              | --                   |
| 225                | 12.03 | 2.01 | 2.00 | 8.55               | 58.83              | 4.28              | 5.88             | 6.42             | -                | -                  | 2950 s              | --                   |
| 226                | 12.03 | 2.01 | 2.00 | 8.55               | 58.83              | 4.28              | 5.88             | 3.21             | 3.21             | -                  | 2950 s              | ---                  |
| 227                | 12.03 | 2.01 | 2.00 | 8.55               | 58.83              | 4.28              | 5.88             | 3.21             | -                | 3.21               | 2950 s              | --                   |
| 228                | 12.03 | 2.01 | 2.00 | 8.55               | 58.83              | 4.28              | 5.88             | 2.14             | 2.14             | 2.14               | 2950 s              | --                   |
| 229                | 12.03 | 2.01 | 2.00 | 8.55               | 58.83              | 4.28              | 5.88             | -                | 6.42             | -                  | 2950 s              | --                   |
| 230                | 12.03 | 2.01 | 2.00 | 8.55               | 58.83              | 4.28              | 5.88             | -                | 3.21             | 3.21               | 2950 s              | --                   |
| 231                | 12.03 | 2.00 | 1.99 | 8.55               | 58.83              | 4.28              | 5.88             | -                | -                | 6.42               | 2950 s              | --                   |
| 232                | 11.97 | 2.00 | 1.99 | 12.77              | 53.18              | 6.38              | 5.32             | 6.38             | -                | -                  | 2950 s              | --                   |
| 233                | 11.97 | 2.00 | 1.99 | 12.77              | 53.18              | 6.38              | 5.32             | 3.19             | 3.19             | -                  | 2950 s              | --                   |
| 234                | 11.97 | 2.00 | 1.99 | 12.77              | 53.18              | 6.38              | 5.32             | 3.10             | -                | 3.19               | 2950 s              | --                   |
| 235                | 11.97 | 2.00 | 1.99 | 12.77              | 53.18              | 6.38              | 5.32             | 2.13             | 2.13             | 2.13               | 2950 s              | --                   |
| 236                | 11.97 | 2.00 | 1.99 | 12.77              | 53.18              | 6.38              | 5.32             | -                | 6.38             | -                  | 2950 s              | --                   |
| 237                | 11.97 | 2.00 | 1.99 | 12.77              | 53.18              | 6.38              | 5.32             | -                | 3.19             | 3.19               | 2950 s              | --                   |
| 238                | 11.97 | 2.00 | 1.99 | 12.77              | 53.18              | 6.38              | 5.32             | -                | -                | 6.38               | 2950 s              | --                   |
| 239                | 11.66 | 1.95 | 1.94 | 12.43              | 57.00              | 6.22              | 5.70             | 3.11             | -                | -                  | 2950 s              | --                   |
| 240                | 11.66 | 1.95 | 1.94 | 12.43              | 57.00              | 6.22              | 5.70             | 1.55             | 1.55             | -                  | 2950 s              | --                   |

TABLE I. (Cont.)

## EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | AlO <sub>1.5</sub> | KO <sub>0.5</sub> | ZrO <sub>2</sub> | TiO <sub>2</sub> | MnO <sub>2</sub> | FeO <sub>1.5</sub> | SiO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|--------------------|-------------------|------------------|------------------|------------------|--------------------|------------------|----------------------|-----------------------|
| 241                | 11.66 | 1.95 | 1.94 | 12.43              | 57.00              | 6.22              | 5.70             | 1.55             | -                | 1.55               | -                | 2950 s               | --                    |
| 242                | 11.66 | 1.95 | 1.94 | 12.43              | 57.00              | 6.22              | 5.70             | 1.04             | 1.04             | 1.04               | -                | 2950 s               | --                    |
| 243                | 11.66 | 1.95 | 1.94 | 12.43              | 57.00              | 6.22              | 5.70             | -                | 3.11             | -                  | -                | 2950 s               | --                    |
| 244                | 11.66 | 1.95 | 1.94 | 12.43              | 57.00              | 6.22              | 5.70             | -                | 1.55             | 1.55               | -                | 2950 s               | --                    |
| 245                | 11.66 | 1.95 | 1.94 | 12.43              | 57.00              | 6.22              | 5.70             | -                | -                | 3.11               | -                | 2950 s               | --                    |
| 246                | 9.32  | 1.55 | 1.55 | 12.43              | 57.00              | 6.22              | 5.70             | 6.22             | -                | -                  | -                | 2950 s               | --                    |
| 247                | 9.32  | 1.55 | 1.55 | 12.43              | 57.00              | 6.22              | 5.70             | 3.11             | 3.11             | -                  | -                | 2950 s               | --                    |
| 248                | 9.32  | 1.55 | 1.55 | 12.43              | 57.00              | 6.22              | 5.70             | 3.11             | -                | 3.11               | -                | 2950 s               | --                    |
| 249                | 9.32  | 1.55 | 1.55 | 12.43              | 57.00              | 6.22              | 5.70             | 2.07             | 2.07             | 2.07               | -                | 2950 s               | --                    |
| 250                | 9.32  | 1.55 | 1.55 | 12.43              | 57.00              | 6.22              | 5.70             | -                | 6.22             | -                  | -                | 2950 s               | --                    |
| 251                | 9.32  | 1.55 | 1.55 | 12.43              | 57.00              | 6.22              | 5.70             | -                | 3.11             | 3.11               | -                | 2950 s               | --                    |
| 252                | 9.32  | 1.55 | 1.52 | 12.43              | 57.00              | 6.22              | 5.70             | -                | -                | 6.22               | -                | 2950 s               | --                    |
| 253                | 19.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | 3.41             | -                | -                  | 1.00             | 2870 g               | 2350                  |
| 254                | 18.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | 3.41             | -                | -                  | 2.00             | 2800 g               | 2100                  |
| 255                | 17.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | 3.41             | -                | -                  | 3.00             | 2850 d               | 2700                  |
| 256                | 16.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | 3.41             | -                | -                  | 4.00             | 2900 d               | 2400                  |
| 257                | 15.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | 3.41             | -                | -                  | 5.00             | 2850 d               | 2400                  |
| 258                | 14.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | 3.41             | -                | -                  | 6.00             | 2950 s               | --                    |
| 259                | 13.45 | 3.41 | 3.41 | 4.55               | 56.82              | 2.27              | 5.68             | 3.41             | -                | -                  | 7.00             | 2950 s               | --                    |
| 260                | 19.75 | 3.29 | 3.29 | 6.36               | 57.25              | 3.18              | 5.58             | 2.29             | -                | -                  | -                | 2750 g               | 2250                  |

TABLE I. (Cont.)

## EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | ZrO <sub>2</sub> | TiO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 261                | 20.45 | 3.41 | 3.41 | 4.55               | 2.27              | 56.82              | 6.80             | 2.29             | 2750 g               | 2350                  |
| 262                | 20.45 | 3.41 | 3.41 | 4.55               | 2.27              | 57.94              | 5.68             | 2.29             | 2750 g               | 2220                  |
| 263                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 59.00              | 5.50             | 2.00             | 2750 g               | 2300                  |
| 264                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 58.00              | 6.50             | 2.00             | 2800 g               | 2300                  |
| 265                | 20.00 | 3.50 | 3.50 | 4.00               | 2.50              | 58.00              | 6.50             | 2.00             | 2750 g               | 2250                  |
| 266                | 19.00 | 3.50 | 3.50 | 4.00               | 2.50              | 58.00              | 6.50             | 3.00             | 2750 g               | 2300                  |
| 267                | 19.00 | 3.50 | 3.50 | 4.00               | 2.50              | 59.00              | 6.50             | 2.00             | 2750 g               | 2350                  |
| 268                | 19.00 | 3.50 | 3.50 | 4.00               | 2.50              | 58.00              | 7.50             | 2.00             | 2850 g               | 2300                  |
| 269                | 18.00 | 3.50 | 3.50 | 4.00               | 2.50              | 59.00              | 7.50             | 2.00             | 2920 pd              | 2550                  |
| 270                | 18.00 | 4.50 | 2.50 | 4.00               | 2.50              | 59.00              | 7.50             | 2.00             | 2880 g               | 2550                  |
| 271                | 17.50 | 4.50 | 2.50 | 4.00               | 2.50              | 59.00              | 7.50             | 2.50             | 2900 g               | 2500                  |
| 272                | 17.00 | 4.50 | 2.50 | 4.00               | 2.50              | 59.00              | 7.50             | 3.00             | 2920 g               | 2650                  |
| 273                | 17.00 | 4.50 | 3.00 | 4.00               | 2.50              | 59.00              | 7.50             | 2.50             | 2970 d               | 2600                  |
| 274                | 16.50 | 4.50 | 3.50 | 4.00               | 2.50              | 59.00              | 7.50             | 2.50             | 2850 d               | 2500                  |
| 275                | 16.00 | 4.50 | 3.00 | 4.00               | 2.50              | 59.00              | 7.50             | 3.50             | 2960 d               | 2650                  |
| 276                | 16.00 | 4.50 | 2.50 | 4.00               | 2.50              | 59.50              | 7.50             | 3.50             | 2970 s               | --                    |
| 277                | 19.00 | 4.50 | 2.50 | 4.00               | 2.50              | 59.59              | 4.50             | 3.50             | 2980 d               | 2450                  |
| 278                | 18.50 | 4.50 | 2.50 | 4.00               | 2.50              | 60.00              | 4.50             | 3.50             | 2900 d               | 2500                  |
| 279                | 19.50 | 4.50 | 1.50 | 4.00               | 2.50              | 60.00              | 4.50             | 3.50             | 2980 d               | 2500                  |
| 280                | 18.50 | 4.50 | 2.50 | 4.00               | 2.50              | 59.00              | 7.50             | 1.50             | 2950 g               | 2500                  |

WADC

TR 55-290

21

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | ZrO <sub>2</sub> | TiO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 281                | 18.00 | 4.50 | 2.50 | 4.00               | 2.50              | 60.00              | 7.50             | 1.00             | 2900 g               | 2500                  |
| 282                | 18.50 | 4.50 | 2.50 | 4.00               | 2.50              | 59.00              | 7.00             | 2.00             | 2900 g               | 2500                  |
| 283                | 18.00 | 4.50 | 2.50 | 4.00               | 2.50              | 59.00              | 7.50             | 2.00             | 2900 g               | 2540                  |
| 284                | 17.00 | 4.50 | 2.00 | 4.00               | 2.50              | 59.50              | 8.00             | 2.50             | 2970 s               | --                    |
| 285                | 18.50 | 4.50 | 2.00 | 4.00               | 2.50              | 59.50              | 8.00             | 1.00             | 2850 g               | 2450                  |
| 286                | 17.00 | 4.50 | 2.00 | 4.00               | 2.50              | 61.00              | 8.00             | 1.00             | 2900 g               | 2350                  |
| 287                | 17.50 | 4.00 | 2.00 | 4.00               | 3.00              | 60.50              | 8.00             | 1.00             | 2880 g               | 2300                  |
| 288                | 18.00 | 4.00 | 2.00 | 4.00               | 3.00              | 60.00              | 8.00             | 1.00             | 2850 g               | 2400                  |
| 289                | 18.50 | 4.00 | 2.00 | 4.00               | 2.50              | 60.00              | 8.00             | 1.00             | 2900 g               | 2300                  |
| 290                | 17.50 | 4.50 | 2.50 | 4.50               | 3.00              | 59.00              | 7.50             | 1.50             | 2800 g               | 2300                  |
| 291                | 17.00 | 4.00 | 2.50 | 5.00               | 3.50              | 59.00              | 7.50             | 1.50             | 2900 d               | 2600                  |
| 292                | 16.50 | 4.00 | 2.00 | 5.50               | 4.00              | 59.00              | 7.50             | 1.50             | 2800 d               | 2600                  |
| 293                | 16.00 | 4.00 | 2.00 | 6.50               | 4.00              | 59.00              | 7.50             | 1.00             | 2950 g               | 2450                  |
| 294                | 15.50 | 3.50 | 2.00 | 7.00               | 4.50              | 59.00              | 7.50             | 1.00             | 2825 g               | 2400                  |
| 295                | 15.00 | 3.50 | 1.50 | 8.00               | 4.50              | 59.00              | 7.50             | 1.00             | 2850 d               | 2300                  |
| 296                | 14.00 | 3.50 | 1.50 | 8.50               | 5.00              | 59.00              | 7.50             | 1.00             | 2950 d               | 2700                  |
| 297                | 13.00 | 3.50 | 1.50 | 9.00               | 5.50              | 59.00              | 7.50             | 1.00             | 2960 s               | --                    |
| 298                | 13.00 | 3.50 | 1.50 | 10.00              | 5.50              | 59.00              | 6.50             | 1.00             | 2980 d               | 2750                  |
| 299                | 13.00 | 3.50 | 1.50 | 10.00              | 6.50              | 59.00              | 5.50             | 1.00             | 2920 d               | 2700                  |
| 300                | 14.10 | 3.30 | 1.40 | 7.50               | 4.20              | 60.50              | 8.00             | 1.00             | 2950 s               | --                    |

WADC TR 55-290

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | ZrO <sub>2</sub> | TiO <sub>2</sub> | SiO <sub>2</sub> | Melting Temp. °F. | Liquidus Temp. °F. |
|-----------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|------------------|-------------------|--------------------|
| 301             | 15.10 | 3.30 | 1.40 | 7.50               | 4.20              | 60.50              | 7.00             | 1.00             | -                | 2950 s            | --                 |
| 302             | 16.10 | 3.30 | 1.40 | 7.50               | 4.20              | 60.50              | 5.00             | 1.00             | -                | 2950 s            | --                 |
| 304             | 15.10 | 3.30 | 1.40 | 6.50               | 4.20              | 60.50              | 8.00             | 1.00             | -                | 2950 s            | --                 |
| 305             | 16.10 | 3.30 | 1.40 | 6.50               | 4.20              | 60.50              | 7.00             | 1.00             | -                | 2950 s            | --                 |
| 306             | 14.10 | 3.30 | 1.40 | 7.50               | 4.20              | 59.50              | 8.00             | 1.00             | 1.00             | 2950 s            | --                 |
| 307             | 14.10 | 3.30 | 1.40 | 7.50               | 4.20              | 58.50              | 8.00             | 1.00             | 2.00             | 2950 s            | --                 |
| 308             | 14.10 | 3.30 | 1.40 | 7.50               | 4.20              | 60.50              | 7.00             | 1.00             | 1.00             | 2950 s            | --                 |
| 309             | 14.10 | 3.30 | 1.40 | 7.50               | 4.20              | 60.50              | 6.00             | 1.00             | 2.00             | 2950 s            | --                 |
| 310             | 30.12 | 3.54 | 1.77 | 6.85               | 2.00              | 53.13              | -                | 2.59             | -                | 2720 g            | 1900               |
| 311             | 30.12 | 3.54 | 1.77 | 5.85               | 3.00              | 53.13              | -                | 2.59             | -                | 2700 g            | 2100               |
| 312             | 29.12 | 3.54 | 1.77 | 5.85               | 3.00              | 53.13              | 1.00             | 2.59             | -                | 2620 g            | 2130               |
| 313             | 29.12 | 3.54 | 1.77 | 5.85               | 3.00              | 53.13              | 2.00             | 1.59             | -                | 2650 g            | 1900               |
| 314             | 29.12 | 3.54 | 1.77 | 5.85               | 3.00              | 52.13              | 3.00             | 1.59             | -                | 2780 g            | 1900               |
| 315             | 28.12 | 3.54 | 1.77 | 5.85               | 3.00              | 52.13              | 4.00             | 1.59             | -                | 2800 g*           | 1950               |
| 316             | 28.12 | 3.54 | 1.77 | 5.85               | 3.00              | 52.13              | 5.00             | 0.59             | -                | 2850 g*           | 2250               |
| 317             | 27.12 | 3.54 | 1.77 | 5.85               | 3.00              | 52.13              | 5.00             | 1.59             | -                | 2900 g*           | 2300               |
| 318             | 26.12 | 3.54 | 1.77 | 5.85               | 3.00              | 53.13              | 5.00             | 1.59             | -                | 2720 g*           | 2150               |
| 319             | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 57.00              | 7.50             | 2.00             | -                | 2830 g*           | 2300               |
| 320             | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 56.00              | 8.50             | 2.00             | -                | 2950 s            | --                 |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 321                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 55.00              | 2.00             | 9.50             | 2950 s               | --                    |
| 322                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 54.00              | 2.00             | 10.50            | 2950 s               | --                    |
| 323                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 53.00              | 2.00             | 11.50            | 2950 s               | --                    |
| 324                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 52.00              | 2.00             | 12.50            | 2950 s               | --                    |
| 325                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 51.00              | 2.00             | 13.50            | 2950 s               | --                    |
| 326                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 50.00              | 2.00             | 14.50            | 2950 s               | --                    |
| 327                | 20.00 | 3.50 | 3.50 | 3.50               | 2.00              | 49.00              | 2.00             | 15.50            | 2950 s               | --                    |
| 328                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 48.00              | 2.00             | 16.50            | 2950 s               | --                    |
| 329                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 47.00              | 2.00             | 17.50            | 2950 s               | --                    |
| 330                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 46.00              | 2.00             | 18.50            | 2950 s               | --                    |
| 331                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 45.00              | 2.00             | 19.50            | 2950 s               | --                    |
| 332                | 20.00 | 3.50 | 3.50 | 4.50               | 2.00              | 44.00              | 2.00             | 20.50            | 2950 s               | --                    |
| 333                | 31.12 | 3.54 | 1.77 | 6.85               | 2.00              | 53.13              | 1.59             | -                | 2420 g*              | 1900                  |
| 334                | 30.12 | 3.54 | 1.77 | 5.85               | 3.00              | 53.13              | 2.59             | -                | 2650 g*              | 1900                  |
| 335                | 31.12 | 3.54 | 0.77 | 6.85               | 2.00              | 53.13              | 2.59             | -                | 2500 g*              | 2000                  |
| 336                | 31.12 | 3.54 | 1.77 | 6.85               | 2.00              | 52.13              | 2.59             | -                | 2500 g               | 1950                  |
| 337                | 31.12 | 3.54 | 1.77 | 6.85               | 2.00              | 51.13              | 2.59             | 1.00             | 2425 g               | 2350                  |
| 338                | 31.12 | 3.54 | 1.77 | 6.85               | 2.00              | 50.03              | 2.59             | 2.00             | 2550 g               | 2450                  |
| 339                | 31.12 | 3.54 | 1.77 | 6.85               | 2.00              | 51.13              | 1.59             | 2.00             | 2570 g               | 1900                  |
| 340                | 32.12 | 3.54 | 0.77 | 5.85               | 3.00              | 50.13              | 1.59             | 3.00             | 2680 g*              | 2240                  |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 341                | 33.12 | 2.54 | 0.77 | 5.05               | 3.00              | 50.13              | 1.59             | 3.00             | 2740 g*              | 2240                  |
| 342                | 32.12 | 2.54 | 0.77 | 5.85               | 3.00              | 50.13              | 1.59             | 4.00             | 2800 d               | 2050                  |
| 343                | 31.12 | 2.54 | 0.77 | 5.85               | 3.00              | 50.13              | 1.59             | 5.00             | 2850 d               | 2700                  |
| 345                | 30.12 | 3.54 | 1.77 | 7.85               | 2.00              | 51.13              | 1.59             | 2.00             | 2550 g               | 2350                  |
| 346                | 30.12 | 3.04 | 1.27 | 7.85               | 3.00              | 51.13              | 1.59             | 2.00             | 2600 g               | 2400                  |
| 347                | 31.12 | 3.04 | 1.27 | 7.85               | 3.00              | 50.13              | 1.59             | 2.00             | 2580 g               | 2350                  |
| 348                | 31.12 | 3.04 | 1.27 | 7.85               | 3.00              | 49.13              | 1.59             | 3.00             | 2700 g*              | 2550                  |
| 349                | 31.12 | 3.04 | 1.27 | 7.85               | 3.00              | 50.13              | 0.59             | 3.00             | 2800 g*              | 2550                  |
| 350                | 31.12 | 3.04 | 1.77 | 7.85               | 3.00              | 49.13              | 1.09             | 3.00             | 2750 g*              | 2450                  |
| 351                | 31.12 | 3.54 | 1.27 | 7.85               | 3.00              | 49.13              | 1.09             | 3.00             | 2950 d               | --                    |
| 352                | 30.12 | 3.54 | 1.27 | 8.85               | 3.00              | 49.13              | 1.09             | 4.00             | 2950 s               | --                    |
| 353                | 30.12 | 3.04 | 0.77 | 8.85               | 3.00              | 49.13              | 1.09             | 5.00             | 2950 s               | --                    |
| 354                | 31.12 | 3.04 | 0.77 | 8.85               | 3.00              | 48.13              | 1.09             | 5.00             | 2950 s               | --                    |
| 355                | 31.12 | 3.04 | 1.27 | 7.85               | 3.00              | 48.13              | 2.59             | 3.00             | 2950 d               | --                    |
| 356                | 31.12 | 3.04 | 1.27 | 7.85               | 3.00              | 48.63              | 2.09             | 3.00             | 2950 d               | --                    |
| 357                | 31.12 | 3.04 | 1.27 | 7.85               | 3.00              | 47.63              | 3.09             | 3.00             | 2950 d               | --                    |
| 358                | 30.62 | 3.04 | 1.77 | 7.85               | 3.00              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 359                | 29.62 | 3.04 | 2.77 | 7.85               | 3.00              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 360                | 30.62 | 3.54 | 1.27 | 7.85               | 3.00              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|-------|--------------------|-------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 361                | 29.62 | 4.54 | 1.27  | 7.85               | 3.00              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 362                | 32.12 | 3.04 | 1.27  | 7.85               | 2.00              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 363                | 33.12 | 3.04 | 1.27  | 6.85               | 2.00              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 364                | 33.12 | 4.04 | 1.27  | 6.85               | 1.00              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 365                | 33.12 | 4.04 | 2.27  | 6.35               | 0.50              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 366                | 34.12 | 4.04 | 2.27  | 5.35               | 0.50              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 367                | 35.12 | 4.04 | 2.27  | 4.35               | 0.50              | 49.13              | 1.59             | 3.00             | 2950 d               | --                    |
| 368                | 34.43 | -    | -     | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2650 g               | 2588                  |
| 369                | 32.71 | -    | 1.72  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2640 g               | 2605                  |
| 370                | 30.98 | -    | 3.44  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2620 g               | 2550                  |
| 371                | 29.26 | -    | 5.16  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2650 d               | --                    |
| 372                | 27.54 | -    | 6.87  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2630 d               | --                    |
| 373                | 25.82 | -    | 8.61  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2880 d               | --                    |
| 374                | 24.10 | -    | 10.33 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2960 s               | --                    |
| 375                | 32.71 | 1.72 | -     | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2620 g               | 2576                  |
| 376                | 30.98 | 1.72 | 1.72  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2600 g               | 2560                  |
| 377                | 29.26 | 1.72 | 3.44  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2570 g               | 2480                  |
| 378                | 27.54 | 1.72 | 5.16  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2580 d               | --                    |
| 379                | 25.82 | 1.72 | 6.87  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2700 d               | --                    |
| 380                | 24.12 | 1.72 | 8.61  | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2900 s               | --                    |

WADC TR 55-290

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|------|--------------------|-------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 381                | 30.98 | 3.44  | -    | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2580 g               | 2578                  |
| 382                | 27.54 | 3.44  | 3.44 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2600 g               | 2574                  |
| 383                | 25.82 | 3.44  | 5.16 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2600 d               | --                    |
| 384                | 24.10 | 3.44  | 6.87 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2650 d               | --                    |
| 385                | 29.26 | 5.16  | -    | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2600 g               | --                    |
| 386                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2650 g               | 2550                  |
| 387                | 25.82 | 5.16  | 3.44 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2630 g               | 2550                  |
| 388                | 24.10 | 5.16  | 5.16 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2600 g               | 2630                  |
| 389                | 27.54 | 6.87  | -    | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2680 g               | 2570                  |
| 390                | 25.82 | 6.87  | 1.72 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2730 g               | 2580                  |
| 391                | 24.10 | 6.87  | 3.44 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2580 g               | 2568                  |
| 392                | 25.82 | 8.61  | -    | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2980 s               | --                    |
| 393                | 24.10 | 8.61  | 1.72 | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2900 s               | --                    |
| 394                | 24.10 | 10.33 | -    | 5.85               | 3.00              | 53.13              | 1.59             | 2.00             | 2950 s               | --                    |
| 395                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 56.72              | -                | -                | 2900 g               | 2490                  |
| 396                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 55.58              | -                | 1.13             | 2900 g               | 2465                  |
| 397                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 54.45              | -                | 2.27             | 2900 g               | 2550                  |
| 398                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 53.32              | -                | 3.40             | 2900 s               | 2750                  |
| 399                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 52.18              | -                | 4.54             | 2900 s               | 2750                  |
| 400                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 51.05              | -                | 5.67             | 2900 s               | 2750                  |

TABLE I (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 401                | 21.54 | 5.16 | 1.72 | 5.85               | 3.00              | 55.59              | 1.13             | -                | 2900 g               | 2495                  |
| 402                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 54.45              | 1.13             | 1.13             | 2900 g               | 2445                  |
| 403                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 53.32              | 1.13             | 2.27             | 2900 g               | 2550                  |
| 404                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 52.18              | 1.13             | 3.40             | 2900 s               | 2750                  |
| 405                | 27.54 | 5.16 | 1.72 | 5.05               | 3.00              | 51.05              | 1.13             | 4.54             | 2900 s               | 2750                  |
| 406                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 54.45              | 2.27             | -                | 2900 g               | 2467                  |
| 407                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 53.32              | 2.27             | 1.13             | 2900 g               | 2480                  |
| 408                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 52.18              | 2.27             | 2.27             | 2900 g               | 2515                  |
| 409                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 51.05              | 2.27             | 3.40             | 2900 s               | --                    |
| 410                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 53.32              | 3.40             | -                | 2900 d               | --                    |
| 411                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 52.18              | 3.40             | 1.13             | 2900 d               | --                    |
| 412                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 51.05              | 3.40             | 2.27             | 2900 d               | --                    |
| 413                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 52.18              | 4.54             | -                | 2900 d               | --                    |
| 414                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 51.05              | 4.54             | 1.13             | 2900 d               | --                    |
| 415                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 51.05              | 5.67             | -                | 2900 d               | --                    |
| 416                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 48.78              | -                | 7.94             | 2900 s               | --                    |
| 417                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | -                | 10.21            | 2900 s               | --                    |
| 418                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 48.78              | 2.27             | 5.67             | 2900 s               | --                    |
| 419                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 2.27             | 7.94             | 2900 s               | --                    |
| 420                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 4.54             | 5.67             | 2900 d               | --                    |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 421<br>WADC        | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 4.54             | 5.67             | 2900 s               | --                    |
| 422                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 48.78              | 6.80             | 1.13             | 2900 d               | --                    |
| 423<br>TR          | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 6.80             | 3.40             | 2900 s               | --                    |
| 424<br>55          | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 48.78              | 7.94             | -                | 2900 d               | --                    |
| 425<br>290         | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 45.38              | 7.94             | 3.40             | 2900 s               | --                    |
| 426                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 10.21            | -                | 2900 s               | --                    |
| 427                | 28.00 | 5.25 | 1.75 | 7.27               | 3.73              | 51.84              | 1.08             | 1.08             | 2900 g               | 2455                  |
| 428                | 29.60 | 5.55 | 1.85 | 6.05               | 3.05              | 51.84              | 1.08             | 1.08             | 2900 g               | 2468                  |
| 429<br>29          | 29.60 | 5.55 | 1.85 | 4.63               | 2.35              | 53.76              | 1.12             | 1.12             | 2900 g               | 2440                  |
| 430                | 28.00 | 5.25 | 1.75 | 4.63               | 2.37              | 55.68              | 1.16             | 1.16             | 2900 d               | --                    |
| 431                | 26.40 | 4.95 | 1.65 | 6.05               | 3.05              | 55.68              | 1.16             | 1.16             | 2900 d               | 2500                  |
| 432                | 26.40 | 4.95 | 1.65 | 7.27               | 3.73              | 53.76              | 1.12             | 1.12             | 2900 g               | 2430                  |
| 433                | 28.00 | 5.25 | 1.75 | 8.59               | 4.41              | 49.92              | 1.04             | 1.04             | 2900 g               | 2500                  |
| 434                | 29.60 | 5.55 | 1.85 | 7.27               | 3.73              | 49.92              | 1.04             | 1.04             | 2900 g               | 2490                  |
| 435                | 31.20 | 5.85 | 1.95 | 6.05               | 3.05              | 49.92              | 1.04             | 1.04             | 2900 g               | 2535                  |
| 436                | 31.20 | 5.85 | 1.95 | 4.63               | 2.37              | 51.84              | 1.08             | 1.08             | 2900 g               | 2530                  |
| 437                | 31.20 | 5.85 | 1.95 | 3.30               | 1.70              | 53.76              | 1.12             | 1.12             | 2900 g               | 2486                  |
| 438                | 29.60 | 5.55 | 1.85 | 3.30               | 1.70              | 55.68              | 1.16             | 1.16             | 2900 g               | 2508                  |
| 439                | 28.00 | 5.25 | 1.75 | 3.30               | 1.70              | 57.60              | 1.20             | 1.20             | 2900 d               | --                    |
| 440                | 26.40 | 4.95 | 1.65 | 4.63               | 2.37              | 57.60              | 1.20             | 1.20             | 2900 d               | ---                   |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KaO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | LiO <sub>0.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|--------------------|--------------------|------------------|------------------|--------------------|----------------------|-----------------------|
| 441                | 24.80 | 4.65 | 1.55 | 6.05               | 3.05               | 57.60              | 1.20             | 1.20             | -                  | 2900 d               | --                    |
| 442                | 24.80 | 4.65 | 1.55 | 7.27               | 3.73               | 55.68              | 1.16             | 1.16             | -                  | 2900 d               | --                    |
| 443                | 24.80 | 4.65 | 1.55 | 8.59               | 4.41               | 53.76              | 1.12             | 1.12             | -                  | 2900 d               | --                    |
| 444                | 26.40 | 4.95 | 1.65 | 8.59               | 4.41               | 51.84              | 1.08             | 1.08             | -                  | 2900 d               | --                    |
| 445                | 26.40 | 4.95 | 1.65 | 9.00               | 1.00               | 53.76              | 1.12             | 1.12             | -                  | 2900 g               | 2465                  |
| 446                | 26.40 | 4.95 | 1.65 | 5.00               | 5.00               | 53.76              | 1.12             | 1.12             | -                  | 2900 g               | 2430                  |
| 447                | 26.40 | 4.95 | 1.65 | 3.00               | 7.00               | 53.76              | 1.12             | 1.12             | -                  | 2900 g               | 2458                  |
| 448                | 26.40 | 4.95 | 1.65 | 1.00               | 9.00               | 53.76              | 1.12             | 1.12             | -                  | 2900 g               | 2525                  |
| 449                | 26.40 | 4.95 | 1.65 | 8.00               | -                  | 53.76              | 1.12             | 1.12             | 2.00               | 2900 g               | 2448                  |
| 450                | 26.40 | 4.95 | 1.65 | 6.00               | 2.00               | 53.76              | 1.12             | 1.12             | 2.00               | 2900 g               | 2430                  |
| 451                | 26.40 | 4.95 | 1.65 | 4.00               | 4.00               | 53.76              | 1.12             | 1.12             | 2.00               | 2900 g               | 2408                  |
| 452                | 26.40 | 4.95 | 1.65 | 2.00               | 6.00               | 53.76              | 1.12             | 1.12             | 2.00               | 2900 g               | 2422                  |
| 453                | 26.40 | 4.95 | 1.65 | -                  | 8.00               | 53.76              | 1.12             | 1.12             | 2.00               | 2900 g               | 2460                  |
| 454                | 26.40 | 4.95 | 1.65 | 6.00               | -                  | 53.76              | 1.12             | 1.12             | 4.00               | 2900 g               | 2415                  |
| 455                | 26.40 | 4.95 | 1.65 | 4.00               | 2.00               | 53.76              | 1.12             | 1.12             | 4.00               | 2900 g               | 2435                  |
| 456                | 26.40 | 4.95 | 1.65 | 2.00               | 4.00               | 53.76              | 1.12             | 1.12             | 4.00               | 2900 g               | 2428                  |
| 457                | 26.40 | 4.95 | 1.65 | -                  | 6.00               | 53.76              | 1.12             | 1.12             | 4.00               | 2900 g               | 2405                  |
| 458                | 26.40 | 4.95 | 1.65 | 4.00               | -                  | 53.76              | 1.12             | 1.12             | 6.00               | 2900 g               | 2360                  |
| 459                | 26.40 | 4.95 | 1.65 | 2.00               | 2.00               | 53.76              | 1.12             | 1.12             | 6.00               | 2900 g               | 2380                  |
| 460                | 26.40 | 4.95 | 1.65 | -                  | 4.00               | 53.76              | 1.12             | 1.12             | 6.00               | 2900 g               | 2402                  |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KaO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | LiO <sub>0.5</sub> | SiO <sub>2</sub> | BO <sub>1.5</sub> | Melting Temp. °F. | Liquidus Temp. °F. |
|-----------------|-------|------|------|--------------------|--------------------|--------------------|------------------|------------------|--------------------|------------------|-------------------|-------------------|--------------------|
| 461             | 26.40 | 4.95 | 1.65 | 2.00               | -                  | 53.76              | 1.12             | 1.12             | 8.00               | -                | -                 | 2900 g*           | --                 |
| 462             | 26.40 | 4.95 | 1.65 | 1.00               | 1.00               | 53.76              | 1.12             | 1.12             | 8.00               | -                | -                 | 2900 g*           | --                 |
| 463             | 26.40 | 4.95 | 1.65 | -                  | 2.00               | 53.76              | 1.12             | 1.12             | 8.00               | -                | -                 | 2900 g*           | --                 |
| 464             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 55.59              |                  |                  |                    | 1.13             | -                 | 2900 g*           | 2440               |
| 465             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 54.45              |                  |                  |                    | 2.27             | -                 | 2900 g            | 2417               |
| 466             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 53.32              |                  |                  |                    | 3.40             | -                 | 2900 g            | 2427               |
| 467             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 52.18              |                  |                  |                    | 4.54             | -                 | 2900 g            | 2406               |
| 468             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 51.05              |                  |                  |                    | 5.67             | -                 | 2900 g            | 2463               |
| 469             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 55.59              |                  |                  |                    | -                | 1.13              | 2900 g            | 2450               |
| 470             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 54.45              |                  |                  |                    | 1.13             | 1.13              | 2900 g            | 2470               |
| 471             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 53.32              |                  |                  |                    | 2.27             | 1.13              | 2900 g            | 2448               |
| 472             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 52.18              |                  |                  |                    | 3.40             | 1.13              | 2900 g            | 2371               |
| 473             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 51.05              |                  |                  |                    | 4.54             | 1.13              | 2900 g            | 2338               |
| 474             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 54.45              |                  |                  |                    | -                | 2.27              | 2900 g            | 2445               |
| 475             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 53.32              |                  |                  |                    | 1.13             | 2.27              | 2900 g            | 2380               |
| 476             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 52.18              |                  |                  |                    | 2.27             | 2.27              | 2900 g            | 2409               |
| 477             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 51.05              |                  |                  |                    | 3.40             | 2.27              | 2900 g            | 2382               |
| 478             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 53.32              |                  |                  |                    | -                | 3.40              | 2900 g            | 2423               |
| 479             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 52.18              |                  |                  |                    | 1.13             | 3.40              | 2900 g            | 2389               |
| 480             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 51.05              |                  |                  |                    | 2.27             | 3.40              | 2900 g            | 2396               |
| 481             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 52.18              |                  |                  |                    | -                | 4.54              | were not melted   |                    |
| 482             | 27.54 | 5.16 | 1.72 | 5.85               | 3.00               | 51.05              |                  |                  |                    | 1.13             | 4.54              | were not melted   |                    |

WADC TR 55-290

TABLE I. (Cont.)

## EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | LiO <sub>0.5</sub> | BO <sub>1.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|--------------------|-------------------|----------------------|-----------------------|
| 483                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 51.05              | -                | -                | -                  | 5.67              | were not melted      |                       |
| 484                | 27.06 | 3.96 | 1.98 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               | -                 | 2900 g               | 2388                  |
| 485                | 26.40 | 3.96 | 2.64 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2388                  |
| 486                | 27.06 | 4.62 | 1.32 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2398                  |
| 487                | 26.40 | 4.62 | 1.98 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2390                  |
| 488                | 25.74 | 4.62 | 2.64 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2390                  |
| 489                | 27.06 | 5.28 | 0.66 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2400                  |
| 490                | 26.40 | 5.28 | 1.32 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2413                  |
| 491                | 25.74 | 5.28 | 1.98 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2406                  |
| 492                | 25.08 | 5.28 | 2.64 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2365                  |
| 493                | 26.40 | 5.94 | 0.66 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2400                  |
| 494                | 25.74 | 5.94 | 1.32 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2398                  |
| 495                | 25.08 | 5.94 | 1.98 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2375                  |
| 496                | 28.38 | 3.96 | 0.66 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g               | 2406                  |
| 497                | 25.08 | 3.96 | 3.96 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g*              | 2380                  |
| 498                | 25.08 | 7.26 | 0.66 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g*              | 2411                  |
| 499                | 23.10 | 6.60 | 3.30 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g*              | 2390                  |
| 500                | 23.10 | 9.24 | 0.66 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g*              | 2390                  |
| 501                | 23.10 | 3.96 | 5.94 | 4.40               | 4.40              | 53.76              | 1.12             | 1.12             | 2.20               |                   | 2900 g*              | 2370                  |

WADC

TR

55-290

32

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | BeO         | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|-------------|----------------------|-----------------------|
| 502                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 49.91              | 6.81             | -                | -           | 2900 g               | 2345                  |
| 503                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 48.78              | 7.94             | -                | -           | 2900 g               | 2338                  |
| 504                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 47.64              | 9.08             | -                | -           | 2900 g               | 2358                  |
| 505                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 49.91              | 5.67             | 1.13             | -           | 2900 g               | 2332                  |
| 505-B              | 24.71 | 5.16 | 1.72 | 5.85               | 3.00              | 49.91              | 5.67             | 1.13             | 2.83        | - g                  | -                     |
| 506                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 48.78              | 6.81             | 1.13             | -           | 2900 g               | 2325                  |
| 506-B              | 24.14 | 5.16 | 1.72 | 5.85               | 3.00              | 48.78              | 6.81             | 1.13             | 3.40        | - g                  | -                     |
| 507                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | -           | 2900 g               | 2325                  |
| 507-B              | 23.57 | 5.16 | 1.72 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 3.97        | - g                  | -                     |
| 508                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -           | 2900 g               | 2438                  |
| 508-B              | 23.00 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | 4.54        | - g                  | -                     |
| 509                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 45.38              | 10.21            | 1.13             | -           | 2900 g               | 2445                  |
| 509-B              | 22.44 | 5.16 | 1.72 | 5.85               | 3.00              | 45.38              | 10.21            | 1.13             | 5.10        | - g                  | -                     |
| 510                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 49.91              | 4.54             | 2.27             | -           | 2900 g               | 2302                  |
| 511                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 48.78              | 5.67             | 2.27             | -           | 2900 g               | 2290                  |
| 512                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 47.64              | 6.81             | 2.27             | -           | 2900 g               | 2330                  |
| 513                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 7.94             | 2.27             | -           | 2900 g               | 2330                  |
| 514                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | 45.38              | 9.08             | 2.27             | -           | 2900 g               | 2340                  |
| 515                | 24.79 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.12             | ZnO<br>2.75 | 2900 d               | 2750                  |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | ZrO <sub>2</sub> | PbO                        | ZnO   | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|------------------|------------------|----------------------------|-------|----------------------|-----------------------|
| WADC 516           | 22.03 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | -                          | 5.51  | 2900 d               | 2850                  |
| TR 517             | 19.28 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | -                          | 8.26  | 2900 d               | 2850                  |
| 55-290 518         | 16.52 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | -                          | 11.02 | 2900 s               | --                    |
| 519                | 13.77 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | -                          | 13.77 | 2900 s               | --                    |
| 520                | 11.02 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | -                          | 16.52 | 2900 s               | --                    |
| 521                | 24.79 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 2.75                       | -     | 2900 d               | 2750                  |
| 522                | 22.03 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 2.75                       | 2.75  | 2900 d               | 2850                  |
| 34 523             | 19.28 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 2.75                       | 5.51  | 2900 d               | 2850                  |
| 524                | 16.52 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 2.75                       | 8.26  | 2900 d               | --                    |
| 525                | 13.77 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 2.75                       | 11.02 | 2900 dm              | --                    |
| 526                | 11.02 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 2.75                       | 13.77 | 2900 dm              | --                    |
| 527                | 22.03 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 5.51                       | -     | 2900 dm              | --                    |
| 528                | 19.28 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 5.51                       | 2.75  | 2900 dm              | --                    |
| 529                | 16.52 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 5.51                       | 5.51  | 2900 dm              | --                    |
| 530                | 13.77 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 5.51                       | 8.26  | 2900 dm              | --                    |
| 531                | 11.02 | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | -                | 5.51                       | 11.02 | 2900 dm              | --                    |
| 532                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 56.00              | -                | -                | -                | LiO <sub>0.5</sub><br>4.40 | 12.54 | 2900 d               | --                    |
| 533                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 54.88              | -                | -                | 1.12             | 4.40                       | 12.54 | 2900 d               | --                    |
| 534                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 53.76              | -                | -                | 2.24             | 4.40                       | 12.54 | 2900 d               | --                    |
| 535                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 52.64              | -                | -                | 3.36             | 4.40                       | 12.54 | 2900 d               | --                    |

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | LiO <sub>0.5</sub>       | TiO <sub>2</sub>                      | ZrO <sub>2</sub> | CaF <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|--------------------------|---------------------------------------|------------------|------------------|----------------------|-----------------------|
| 536                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 51.52              | 4.40                     | -                                     | 4.48             | 12.54            | 2900 g*              | --                    |
| 537                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 50.40              | 4.40                     | -                                     | 5.60             | 12.54            | 2900 g*              | --                    |
| 538                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 54.88              | 4.40                     | 1.12                                  | -                | 12.54            | 2900 d               | --                    |
| 539                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 52.64              | 4.40                     | 1.12                                  | 2.24             | 12.54            | 2900 d               | --                    |
| 540                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 51.52              | 4.40                     | 1.12                                  | 3.36             | 12.54            | 2900 d               | --                    |
| 541                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 50.40              | 4.40                     | 1.12                                  | 4.48             | 12.54            | 2900 g*              | --                    |
| 542                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 53.76              | 4.40                     | 2.24                                  | -                | 12.54            | 2900 d               | --                    |
| 543                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 52.64              | 4.40                     | 2.24                                  | 1.12             | 12.54            | 2900 d               | --                    |
| 544                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 51.52              | 4.40                     | 2.24                                  | 2.24             | 12.54            | 2900 d               | ---                   |
| 545                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 50.40              | 2.20                     | 2.24                                  | 3.36             | 12.54            | 2900 d               | --                    |
| 546                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 52.64              | 2.20                     | 3.36                                  | -                | 12.54            | 2900 d               | --                    |
| 547                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 51.52              | 2.20                     | 3.36                                  | 1.12             | 12.54            | 2900 d               | --                    |
| 548                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 50.40              | 2.20                     | 3.36                                  | 2.24             | 12.54            | 2900 d               | --                    |
| 549                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 51.52              | 2.20                     | 4.48                                  | -                | 12.54            | 2900 d               | --                    |
| 550                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 50.40              | 2.20                     | 4.48                                  | 1.12             | 12.54            | 2900 d               | --                    |
| 551                | 12.54 | 5.28 | 2.64 | 4.40               | 4.40              | 50.40              | 2.20                     | 5.60                                  | -                | 12.54            | 2900 d               | --                    |
| 552                | 8.26  | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | SiO <sub>2</sub><br>9.08 | B <sub>2</sub> O <sub>3</sub><br>1.13 | ZnO<br>19.28     |                  | 2900 s               | --                    |
| 553                | 5.51  | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08                     | 1.13                                  | 22.03            |                  | 2900 s               | --                    |
| 554                | 2.75  | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08                     | 1.13                                  | 24.79            |                  | 2900 s               | --                    |
| 555                |       | 5.16 | 1.72 | 5.85               | 3.00              | 46.51              | 9.08                     | 1.13                                  | 27.54            |                  | 2900 s               | --                    |

WADC

H<sub>2</sub>R

55-290

35

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO  | MgO  | BaO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | ZnO   | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|------|------|-------|--------------------|-------------------|--------------------|------------------|------------------|-------|----------------------|-----------------------|
| 552                | 9.81 | 1.72 | -     | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 22.89 | 2900 s               | --                    |
| 553                | 9.29 | 1.72 | 1.72  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 21.69 | 2900 s               | --                    |
| 554                | 8.78 | 1.72 | 3.44  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 20.48 | 2900 s               | --                    |
| 555                | 8.26 | 1.72 | 5.16  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 19.28 | 2900 s               | --                    |
| 556                | 7.75 | 1.72 | 6.88  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 18.07 | 2900 s               | --                    |
| 557                | 7.23 | 1.72 | 8.60  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 16.86 | 2900 s               | --                    |
| 558                | 6.71 | 1.72 | 10.33 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 15.66 | 2900 s               | --                    |
| 559                | 6.20 | 1.72 | 12.05 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 14.46 | 2900 s               | --                    |
| 560                | 5.68 | 1.72 | 13.77 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 13.25 | 2900 s               | --                    |
| 561                | 5.16 | 1.72 | 15.49 | 5.85               | 3.00              | 47.64              | 5.94             | 1.13             | 12.04 | 2900 s               | --                    |
| 562                | 9.29 | 3.44 | -     | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 21.69 | 2900 s               | --                    |
| 563                | 8.78 | 3.44 | 1.72  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 20.48 | 2900 s               | --                    |
| 564                | 8.26 | 3.44 | 3.44  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 19.28 | 2900 s               | --                    |
| 565                | 7.75 | 3.44 | 5.16  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 18.07 | 2900 s               | --                    |
| 566                | 7.23 | 3.44 | 6.88  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 16.86 | 2900 s               | --                    |
| 567                | 6.71 | 3.44 | 8.60  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 15.66 | 2900 s               | --                    |
| 568                | 6.20 | 3.44 | 10.33 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 14.46 | 2900 s               | --                    |
| 569                | 5.68 | 3.44 | 12.05 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 13.25 | 2900 s               | --                    |
| 570                | 5.16 | 3.44 | 13.77 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 12.04 | 2900 s               | --                    |
| 571                | 8.78 | 5.16 | -     | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 20.48 | 2900 s               | --                    |

TABLE I. (Cont.)

## EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO  | MgO  | BaO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | ZnO   | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|------|------|-------|--------------------|-------------------|--------------------|------------------|------------------|-------|----------------------|-----------------------|
| 572                | 8.26 | 5.16 | 1.72  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 19.28 | 2900 s               | --                    |
| 573                | 7.75 | 5.16 | 3.44  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 13.25 | 2900 s               | --                    |
| 570                | 5.16 | 3.44 | 13.77 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 12.04 | 2900 s               | --                    |
| 571                | 8.78 | 5.16 | -     | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 20.48 | 2900 s               | --                    |
| 572                | 8.26 | 5.16 | 1.72  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 19.28 | 2900 s               | --                    |
| 573                | 7.75 | 5.16 | 3.44  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 18.07 | 2900 s               | --                    |
| 574                | 7.23 | 5.16 | 5.16  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 16.86 | 2900 s               | --                    |
| 575                | 6.71 | 5.16 | 6.88  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 15.66 | 2900 s               | --                    |
| 576                | 6.20 | 5.16 | 8.60  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 14.46 | 2900 s               | --                    |
| 577                | 5.68 | 5.16 | 10.33 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 13.25 | 2900 s               | --                    |
| 578                | 5.16 | 5.16 | 12.05 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 12.04 | 2900 s               | --                    |
| 579                | 8.26 | 6.88 | -     | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 19.28 | 2900 s               | --                    |
| 580                | 7.75 | 6.88 | 1.72  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 18.07 | 2900 s               | --                    |
| 581                | 7.23 | 6.88 | 3.44  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 16.86 | 2900 s               | --                    |
| 582                | 6.71 | 6.88 | 5.16  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 15.66 | 2900 s               | --                    |
| 583                | 6.20 | 6.88 | 6.88  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 14.46 | 2900 s               | --                    |
| 584                | 5.68 | 6.88 | 8.60  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 13.25 | 2900 s               | --                    |
| 585                | 5.16 | 6.88 | 10.33 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 12.04 | 2900 s               | --                    |
| 586                | 7.75 | 8.60 | -     | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 18.07 | 2900 s               | --                    |
| 587                | 7.23 | 8.60 | 1.72  | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 16.86 | 2900 s               | --                    |

WADC TR 55-290

TABLE I. (Cont.)  
EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | ZnO   | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|------|--------------------|-------------------|--------------------|------------------|------------------|-------|----------------------|-----------------------|
| 588                | 6.71  | 8.60  | 3.44 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 15.66 | 2900 s               | --                    |
| 589                | 6.20  | 8.60  | 5.16 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 14.46 | 2900 s               | --                    |
| 590                | 5.68  | 8.60  | 6.88 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 13.25 | 2900 s               | --                    |
| 591                | 5.16  | 8.60  | 8.60 | 5.85               | 3.00              | 47.64              | 7.94             | 1.13             | 12.04 | 2900 s               | --                    |
| 592                | 6.30  | 6.00  | 3.00 | 3.31               | 1.70              | 54.60              | 9.10             | 1.30             | 14.70 | 2900 s               | --                    |
| 593                | 7.35  | 7.00  | 3.50 | 3.31               | 1.70              | 50.40              | 8.40             | 1.20             | 17.15 | 2900 s               | --                    |
| 594                | 8.40  | 8.00  | 4.00 | 3.31               | 1.70              | 46.20              | 7.70             | 1.10             | 19.60 | 2900 s               | --                    |
| 595                | 9.45  | 9.00  | 4.50 | 3.31               | 1.70              | 42.00              | 7.00             | 1.00             | 22.05 | 2900 s               | --                    |
| 596                | 10.50 | 10.00 | 5.00 | 3.31               | 1.70              | 37.80              | 6.30             | 0.90             | 24.50 | 2900 s               | --                    |
| 597                | 11.55 | 11.00 | 5.50 | 3.31               | 1.70              | 33.60              | 5.60             | 0.80             | 26.95 | 2900 s               | --                    |
| 598                | 5.78  | 5.50  | 2.75 | 4.96               | 2.54              | 54.60              | 9.10             | 1.30             | 13.48 | 2900 s               | --                    |
| 599                | 6.83  | 6.50  | 3.25 | 4.96               | 2.54              | 50.40              | 8.40             | 1.20             | 15.93 | 2900 s               | --                    |
| 600                | 7.88  | 7.50  | 3.75 | 4.96               | 2.54              | 46.20              | 7.70             | 1.10             | 18.38 | 2900 s               | --                    |
| 601                | 8.93  | 8.50  | 4.25 | 4.96               | 2.54              | 42.00              | 7.00             | 1.00             | 20.83 | 2900 s               | --                    |
| 602                | 9.98  | 9.50  | 4.75 | 4.96               | 2.54              | 37.80              | 6.30             | 0.90             | 23.28 | 2900 s               | --                    |
| 603                | 11.03 | 10.50 | 5.25 | 4.96               | 2.54              | 33.60              | 5.60             | 0.80             | 25.73 | 2900 s               | --                    |
| 604                | 5.25  | 5.00  | 2.50 | 6.61               | 3.39              | 54.60              | 9.10             | 1.30             | 12.25 | 2900 s               | --                    |
| 605                | 6.30  | 6.00  | 3.00 | 6.61               | 3.30              | 50.40              | 8.40             | 1.20             | 14.70 | 2900 s               | --                    |
| 606                | 7.35  | 7.00  | 3.50 | 6.61               | 3.39              | 46.20              | 7.70             | 1.10             | 17.15 | 2900 s               | --                    |
| 607                | 8.40  | 8.00  | 4.00 | 6.61               | 3.39              | 42.00              | 7.00             | 1.00             | 19.00 | 2900 s               | --                    |

TABLE I. (Cont.)

## EXPLORATORY CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | ZnO   | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|------|--------------------|-------------------|--------------------|------------------|------------------|-------|----------------------|-----------------------|
| 608                | 9.45  | 9.00  | 4.50 | 6.61               | 3.39              | 37.80              | 6.30             | 0.90             | 22.05 | 2900 s               | --                    |
| 609                | 10.50 | 10.00 | 5.00 | 6.61               | 3.39              | 33.60              | 5.60             | 0.80             | 24.50 | 2900 s               | --                    |
| 610                | 4.73  | 4.50  | 2.25 | 8.26               | 4.24              | 54.60              | 9.10             | 1.30             | 11.03 | 2900 s               | --                    |
| 611                | 5.78  | 5.50  | 2.75 | 8.26               | 4.24              | 50.40              | 8.40             | 1.20             | 13.48 | 2900 s               | --                    |
| 612                | 6.83  | 6.50  | 3.25 | 8.26               | 4.24              | 46.20              | 7.70             | 1.10             | 15.93 | 2900 s               | --                    |
| 613                | 7.88  | 7.50  | 3.75 | 8.26               | 4.24              | 42.00              | 7.00             | 1.00             | 18.38 | 2900 s               | --                    |
| 614                | 8.93  | 8.50  | 4.25 | 8.26               | 4.24              | 37.80              | 6.30             | 0.90             | 20.83 | 2900 s               | --                    |
| 615                | 9.98  | 9.50  | 4.75 | 8.26               | 4.24              | 33.60              | 5.60             | 0.80             | 23.28 | 2900 s               | --                    |
| 616                | 4.20  | 4.00  | 2.00 | 9.92               | 5.09              | 54.60              | 9.10             | 1.30             | 9.80  | 2900 s               | --                    |
| 617                | 5.25  | 5.00  | 2.50 | 9.92               | 5.09              | 50.40              | 8.40             | 1.20             | 12.25 | 2900 s               | --                    |
| 618                | 6.30  | 6.00  | 3.00 | 9.92               | 5.09              | 46.20              | 7.70             | 1.10             | 14.70 | 2900 s               | --                    |
| 619                | 7.35  | 7.00  | 3.50 | 9.92               | 5.09              | 42.00              | 7.00             | 1.00             | 17.15 | 2900 s               | --                    |
| 620                | 8.40  | 8.00  | 4.00 | 9.92               | 5.09              | 37.80              | 6.30             | 0.90             | 19.60 | 2900 s               | --                    |
| 621                | 9.45  | 9.00  | 4.50 | 9.92               | 5.09              | 33.60              | 5.60             | 0.80             | 22.05 | 2900 s               | --                    |
| 622                | 4.73  | 4.50  | 2.75 | 11.57              | 5.93              | 50.40              | 8.40             | 1.20             | 11.03 | 2900 s               | --                    |
| 623                | 5.78  | 5.50  | 2.75 | 11.57              | 5.93              | 46.20              | 7.70             | 1.10             | 13.48 | 2900 s               | --                    |
| 624                | 6.83  | 6.50  | 3.25 | 11.57              | 5.93              | 42.00              | 7.00             | 1.00             | 15.93 | 2900 s               | --                    |
| 625                | 7.88  | 7.50  | 3.75 | 11.57              | 5.93              | 37.80              | 6.30             | 0.90             | 18.38 | 2900 s               | --                    |
| 626                | 8.93  | 8.50  | 4.25 | 11.57              | 5.93              | 33.60              | 5.60             | 0.80             | 20.83 | 2900 s               | --                    |
| 627                | 4.20  | 4.00  | 2.00 | 13.22              | 6.78              | 50.40              | 8.40             | 1.20             | 9.80  | 2900 s               | --                    |

TABLE I (Cont.)

## EXPLORATORY CALCIUM ALUMINA LASSES

| Composition<br>No. | CaO  | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | ZnO   | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|------|------|------|--------------------|-------------------|--------------------|------------------|------------------|-------|----------------------|-----------------------|
| 628                | 5.25 | 5.00 | 2.50 | 13.22              | 6.78              | 46.20              | 7.70             | 1.10             | 12.25 | 2900 s               | --                    |
| 629                | 6.30 | 6.00 | 3.00 | 13.22              | 6.78              | 42.00              | 7.00             | 1.00             | 14.70 | 2900 s               | --                    |
| 630                | 7.35 | 7.00 | 3.50 | 13.22              | 6.78              | 37.80              | 6.30             | 0.90             | 17.15 | 2900 s               | --                    |
| 631                | 8.40 | 8.00 | 4.00 | 13.22              | 6.78              | 33.60              | 5.60             | 0.80             | 19.60 | 2900 s               | --                    |

TABLE II.

## PHYSICAL PROPERTIES OF EXPLORATORY CALCIUM ALUMINATE GLASSES

| Glass No. | log. viscosity in poises |             |             | Specific Gravity<br>gm/ml | Ex 10 <sup>-6</sup><br>psi |
|-----------|--------------------------|-------------|-------------|---------------------------|----------------------------|
|           | 0.5<br>°F.               | 1.00<br>°F. | 1.50<br>°F. |                           |                            |
| 67        | 2825                     | 2575        | 2380        | -                         | -                          |
| 166       | 2725                     | 2500        | 2340        | 3.09                      | 16.1                       |
| 197       | -                        | -           | -           | 3.19                      | 16.7                       |
| 211       | -                        | -           | -           | 3.198                     | 16.4                       |
| 310       | -                        | 2610        | 2430        | -                         | -                          |
| 313       | -                        | 2645        | 2475        | -                         | -                          |
| 314       | -                        | 2650        | 2570        | -                         | -                          |
| 336       | -                        | 2625        | -           | -                         | -                          |
| 339       | -                        | 2615        | 2450        | -                         | -                          |
| 395       | -                        | 2730        | 2525        | 2.91                      | 15.85                      |
| 451       | -                        | 2675        | 2480        | -                         | -                          |
| 472       | -                        | -           | 2520        | -                         | -                          |
| 492       | -                        | 2680        | 2480        | -                         | -                          |
| 506       | -                        | 2700        | 2515        | -                         | -                          |
| 508       | -                        | 2675        | 2485        | 2.91                      | 15.42                      |
| 511       | -                        | 2680        | 2495        | -                         | -                          |
| 505-B     | -                        | 2705        | 2525        | 2.89                      | 15.85                      |
| 506-B     | - Not determined-        |             |             |                           |                            |
| 507-B     | -                        | 2645        | 2460        | 2.90                      | 15.79                      |
| 508-B     | -Not determined-         |             |             |                           |                            |
| 509-B     | -                        | 2700        | 2515        | 2.89                      | 15.76                      |

Small changes in composition were made to outline the areas of glass formation in the calcium aluminate system. All the compositions shown in Table III were melted in small platinum crucibles for this purpose. Large melts of 1500 grams were prepared for physical property measurements. The results of liquidus temperature measurements, Appendix I, viscosity measurements, Appendix II, and Young's modulus measurements, Appendix V for selected compositions of this group are shown in Table IV, page 59. The letter "g" beside the melting temperature in Table III indicates that clear glass was produced in a 10 gram melt of the composition. The letter "d" beside the melting temperature signifies devitrification of a 10 gram melt. These melts were removed from the furnace at the melting temperature and cooled in air. No quenching of the crucible of glass was done. All melting was done in platinum crucibles in a gas fired muffle furnace at temperatures of 2750°F. to 2900°F.

Compositions starting with No. 632 were those which were investigated after the beginning of this contract. These compositions were designed to determine the extent of glass formation in the calcium aluminate system containing small quantities of other alkaline earth oxides, BeO, MgO and BaO; alkaline oxides, Na<sub>2</sub>O, K<sub>2</sub>O and Li<sub>2</sub>O; other acidic components, SiO<sub>2</sub>, B<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub> and ZrO<sub>2</sub>. Small quantities of iron oxide were investigated in a few compositions. The effect of variations of these components on the physical properties of the glass was determined.

Compositions Nos. 632 - 652 were a study of the substitution of MgO and BaO for CaO in glass No. 508. The replacement of CaO by either MgO or BaO up to 20% of the total alkaline earth oxides resulted in clear glasses. Substitutions of more than 20% by either MgO or BaO resulted in melts which devitrified on cooling.

Compositions Nos. 653 - 671 were a study of the substitution of B<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> for Al<sub>2</sub>O<sub>3</sub> in glass No. 508. Substitutions up to 50% of the total acidic components by B<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> resulted in clear glasses.

Compositions Nos. 672 - 692 were a study of the substitution of K<sub>2</sub>O and Li<sub>2</sub>O for Na<sub>2</sub>O in glass No. 508. Clear glasses were found for 100% substitution of Na<sub>2</sub>O by K<sub>2</sub>O and Li<sub>2</sub>O.

Compositions Nos. 693 - 712 were a systematic variation of the three major groups. The acidic group was composed of Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub> and B<sub>2</sub>O<sub>3</sub>. The alkali oxide group was composed of CaO, MgO and BaO. The ratio of Al<sub>2</sub>O<sub>3</sub>:SiO<sub>2</sub>:B<sub>2</sub>O<sub>3</sub> was 6:2:2. The ratio of Na<sub>2</sub>O:K<sub>2</sub>O:Li<sub>2</sub>O was 4:4:2. The ratio of CaO:MgO:BaO was 6:2:2. Glasses were formed of all compositions containing 45% or more acidic components. The glasses containing 45 - 50% acidic components were blue to green in color. The glasses containing more than 50% acidic components were colorless.

Compositions Nos. 713 - 730 were a systematic variation of the major groups with a ratio of  $AlO_{1.5}:SiO_2:BO_{1.5}$  of 6:2:2; a ratio of  $NaO_{0.5}:K0_{0.5}:LiO_{0.5}$  of 4:4:2 and a ratio of  $CaO:MgO:BaO$  of 4:1:0. All compositions containing 50% or more acidic components formed clear glasses. Only composition No. 720 formed a clear glass containing less than 50% acidic components.

Compositions Nos. 731 - 751 were a systematic variation of the major groups with a ratio of  $AlO_{1.5}:SiO_2:BO_{1.5}$  of 6:0:4; a ratio of  $NaO_{0.5}:K0_{0.5}:LiO_{0.5}$  of 4:4:2 and a ratio of  $CaO:MgO:BaO$  of 4:1:0. All compositions containing 45% or more acidic components formed clear glasses without devitrification.

Compositions Nos. 752 - 772 were a systematic variation of the major groups with a  $AlO_{1.5}:SiO_2:BO_{1.5}$  ratio of 6:4:0; a  $NaO_{0.5}:K0_{0.5}:LiO_{0.5}$  ratio of 4:4:2, and a  $CaO:MgO:BaO$  ratio of 4:1:0. All compositions containing 50% or more acidic components and composition No. 767 formed clear glasses without devitrification.

Compositions Nos. 773 - 792 were a systematic variation of the major groups with a  $AlO_{1.5}:SiO_2:BO_{1.5}$  ratio of 6:2:2; a  $NaO_{0.5}:K0_{0.5}:LiO_{0.5}$  ratio of 2:4:4 and a  $CaO:MgO:BaO$  ratio of 4:1:0. All compositions containing 50% or more acidic components formed clear glasses.

Compositions Nos. 792 - 812 were a systematic variation of the major groups. The  $AlO_{1.5}:SiO_2:BO_{1.5}$  ratio was 6:2:2. The  $NaO_{0.5}:K0_{0.5}:LiO_{0.5}$  ratio was 4:2:4. The  $CaO:MgO:BaO$  ratio was 4:1:0. All glasses, except No. 808, which contained 45% acidic components formed clear glasses.

Compositions Nos. 813 - 833 were a systematic variation of the major groups. The  $AlO_{1.5}:SiO_2:BO_{1.5}$  ratio was 6:2:2. The  $NaO_{0.5}:K0_{0.5}:LiO_{0.5}$  ratio was 4:4:2 and the  $CaO:MgO:BaO$  ratio was 4:0:1. All glasses containing 50% acidic components and No. 814 formed clear glasses.

Compositions Nos. 834 - 851 were mixed but never melted because of the high toxicity of  $BeO$  (5, 6) which was one of the constituents.

Compositions Nos. 852 - 861 were substitutions of one constituent for another in an attempt to find a glass which had a low liquidus temperature and greater viscosity.

Compositions Nos. 862 - 891 were substitutions of  $FeO_{1.5}$  for all other constituents in an attempt to lower liquidus temperatures. No glasses were produced in this entire series.

Compositions 892 - 949 were the final attempts to add  $TiO_2$  and  $ZrO_2$  to these compositions. High liquidus temperatures, high melting temperatures and low viscosities were found in nearly all these melts.

TABLE III.

## SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | BaO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | BO <sub>1.5</sub> | Melting<br>T <sub>e</sub> mp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|-------|--------------------|-------------------|--------------------|------------------|-------------------|-----------------------------------|-----------------------|
| 632<br>WADC        | 34.42 | -     | -     | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 g                            | 2460                  |
| 633                | 27.53 | -     | 6.88  | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 g                            | 2460                  |
| 634<br>TR          | 20.65 | -     | 13.77 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 635<br>55          | 13.77 | -     | 20.65 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 636<br>290         | 6.88  | -     | 27.53 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 637                | -     | -     | 34.42 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 638                | 27.53 | 6.88  | -     | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 g                            | 2691                  |
| 639<br>44          | 20.65 | 6.88  | 6.88  | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 g                            | 2640                  |
| 640                | 13.77 | 6.88  | 13.77 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 641                | 6.88  | 6.88  | 20.65 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 642                | -     | 6.88  | 27.53 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 643                | 20.65 | 13.77 | -     | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 644                | 13.77 | 13.77 | 6.88  | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 645                | 6.88  | 13.77 | 13.77 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 646                | -     | 13.77 | 20.65 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 647                | 13.77 | 20.65 | -     | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 648                | 6.88  | 20.65 | 6.88  | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 649                | -     | 20.65 | 13.77 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |
| 650                | 6.88  | 27.53 | -     | 5.85               | 3.00              | 46.51              | 9.08             | 1.13              | 2900 d                            | --                    |

TABLE III. (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | B <sub>1.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|------|--------------------|-------------------|--------------------|------------------|------------------|------------------|----------------------|-----------------------|
| 651                | -     | 27.53 | 6.88 | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | 1.13             | 2900 d               | --                    |
| 652                | -     | 34.42 | -    | 5.85               | 3.00              | 46.51              | 9.08             | 1.13             | 1.13             | 2900 d               | --                    |
| 653                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 45.38              | 11.34            | -                | -                | 2900 g               | 2560                  |
| 654                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 39.70              | 17.02            | -                | -                | 2900 g               | --                    |
| 655                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 34.03              | 22.69            | -                | -                | 2900 g               | --                    |
| 656                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 28.36              | 28.36            | -                | -                | 2900 g               | 2580                  |
| 657                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 51.05              | -                | 5.67             | 5.67             | 2900 g               | 2487                  |
| 658                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 45.38              | 5.67             | 5.67             | 5.67             | 2900 g               | --                    |
| 659                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 39.70              | 11.34            | 5.67             | 5.67             | 2900 g               | 2440                  |
| 660                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 34.03              | 17.02            | 5.67             | 5.67             | 2900 g               | --                    |
| 661                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 28.36              | 22.69            | 5.67             | 5.67             | 2900 g               | 2560                  |
| 662                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 45.38              | -                | 11.34            | 11.34            | 2900 g               | 2465                  |
| 663                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 39.70              | 5.67             | 11.34            | 11.34            | 2900 g               | --                    |
| 664                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 34.03              | 11.34            | 11.34            | 11.34            | 2900 g               | 2450                  |
| 665                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 28.36              | 17.02            | 11.34            | 11.34            | 2900 g               | --                    |
| 666                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 39.70              | -                | 17.02            | 17.02            | 2900 g               | 2300                  |
| 667                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 34.03              | 5.67             | 17.02            | 17.02            | 2900 g               | --                    |
| 668                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 28.36              | 11.34            | 17.02            | 17.02            | 2900 g               | --                    |
| 669                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 34.03              | -                | 22.69            | 22.69            | 2900 g               | --                    |
| 670                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 28.36              | 5.67             | 22.69            | 22.69            | 2900 g               | 2325                  |
| 671                | 27.54 | 5.16  | 1.72 | 5.85               | 3.00              | 28.36              | -                | 28.36            | 28.36            | 2900 g               | --                    |

TABLE III. (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | BO <sub>1.5</sub> | LiO <sub>0.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|------------------|-------------------|--------------------|----------------------|-----------------------|
| 672                | 27.54 | 5.16 | 1.72 | 8.85               | -                 | 46.51              | 9.08             | 1.13              | -                  | 2900 g               | 2600                  |
| 673                | 27.54 | 5.16 | 1.72 | 7.08               | 1.77              | 46.51              | 9.08             | 1.13              | -                  | 2900 g               | --                    |
| 674                | 27.54 | 5.16 | 1.72 | 5.31               | 3.54              | 46.51              | 9.08             | 1.13              | -                  | 2900 g               | --                    |
| 675                | 27.54 | 5.16 | 1.72 | 3.54               | 5.31              | 46.51              | 9.08             | 1.13              | -                  | 2900 g               | 2506                  |
| 676                | 27.54 | 5.16 | 1.72 | 1.77               | 7.08              | 46.51              | 9.08             | 1.13              | -                  | 2900 g               | --                    |
| 677                | 27.54 | 5.16 | 1.72 | -                  | 8.85              | 46.51              | 9.08             | 1.13              | -                  | 2900 g               | 2515                  |
| 678                | 27.54 | 5.16 | 1.72 | 7.08               | -                 | 46.51              | 9.08             | 1.13              | 1.77               | 2900 g               | --                    |
| 679                | 27.54 | 5.16 | 1.72 | 5.31               | 1.77              | 46.51              | 9.08             | 1.13              | 1.77               | 2900 g               | --                    |
| 680                | 27.54 | 5.16 | 1.72 | 3.54               | 3.54              | 46.51              | 9.08             | 1.13              | 1.77               | 2900 g               | --                    |
| 681                | 27.54 | 5.16 | 1.72 | 1.77               | 5.31              | 46.51              | 9.08             | 1.13              | 1.77               | 2900 g               | --                    |
| 682                | 27.54 | 5.16 | 1.72 | -                  | 7.08              | 46.51              | 9.08             | 1.13              | 1.77               | 2900 g               | --                    |
| 683                | 27.54 | 5.16 | 1.72 | 5.31               | -                 | 46.51              | 9.08             | 1.13              | 3.54               | 2900 g               | 2650                  |
| 684                | 27.54 | 5.16 | 1.72 | 3.54               | 1.77              | 46.51              | 9.08             | 1.13              | 3.54               | 2900 g               | --                    |
| 685                | 27.54 | 5.16 | 1.72 | 1.77               | 3.54              | 46.51              | 9.08             | 1.13              | 3.54               | 2900 g               | --                    |
| 686                | 27.54 | 5.16 | 1.72 | -                  | 5.31              | 46.51              | 9.08             | 1.13              | 3.54               | 2900 g               | 2651                  |
| 687                | 27.54 | 5.16 | 1.72 | 3.54               | -                 | 46.51              | 9.08             | 1.13              | 5.31               | 2900 g               | --                    |
| 688                | 27.54 | 5.16 | 1.72 | 1.77               | 1.77              | 46.51              | 9.08             | 1.13              | 5.31               | 2900 g               | 2651                  |
| 689                | 27.54 | 5.16 | 1.72 | -                  | 3.54              | 46.51              | 9.08             | 1.13              | 5.31               | 2900 g               | --                    |
| 690                | 27.54 | 5.16 | 1.72 | 1.77               | -                 | 46.51              | 9.08             | 1.13              | 7.08               | 2900 g               | --                    |
| 691                | 27.54 | 5.16 | 1.72 | -                  | 1.77              | 46.51              | 9.08             | 1.13              | 7.08               | 2900 g               | --                    |
| 692                | 27.54 | 5.16 | 1.72 | -                  | -                 | 46.51              | 9.08             | 1.13              | 8.85               | 2900 g               | 2651                  |

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | BaO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | LiO <sub>0.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|-------|--------------------|-------------------|--------------------|------------------|------------------|--------------------|----------------------|-----------------------|
| 693                | 36.00 | 12.00 | 12.00 | -                  | -                 | 24.00              | 8.00             | 8.00             | -                  | 2900 d               | --                    |
| 694                | 33.00 | 11.00 | 11.00 | -                  | -                 | 27.00              | 9.00             | 9.00             | -                  | 2900 g               | --                    |
| 695                | 30.00 | 10.00 | 10.00 | -                  | -                 | 30.00              | 10.00            | 10.00            | -                  | 2900 g               | 2505                  |
| 696                | 27.00 | 9.00  | 9.00  | -                  | -                 | 33.00              | 11.00            | 11.00            | -                  | 2900 g               | --                    |
| 697                | 24.00 | 8.00  | 8.00  | -                  | -                 | 36.00              | 12.00            | 12.00            | -                  | 2900 g               | --                    |
| 698                | 36.00 | 12.00 | 12.00 | 2.00               | 2.00              | 21.00              | 7.00             | 7.00             | 1.00               | 2900 d               | --                    |
| 699                | 33.00 | 11.00 | 11.00 | 2.00               | 2.00              | 24.00              | 8.00             | 8.00             | 1.00               | 2900 d               | --                    |
| 700                | 30.00 | 10.00 | 10.00 | 2.00               | 2.00              | 27.00              | 9.00             | 9.00             | 1.00               | 2900 g               | --                    |
| 701                | 27.00 | 9.00  | 9.00  | 2.00               | 2.00              | 30.00              | 10.00            | 10.00            | 1.00               | 2900 g               | --                    |
| 702                | 24.00 | 8.00  | 8.00  | 2.00               | 2.00              | 33.00              | 11.00            | 11.00            | 1.00               | 2900 g               | 2350                  |
| 703                | 33.00 | 11.00 | 11.00 | 4.00               | 4.00              | 21.00              | 7.00             | 7.00             | 2.00               | 2900 d               | --                    |
| 704                | 30.00 | 10.00 | 10.00 | 4.00               | 4.00              | 24.00              | 8.00             | 8.00             | 2.00               | 2900 d               | --                    |
| 705                | 27.00 | 9.00  | 9.00  | 4.00               | 4.00              | 27.00              | 9.00             | 9.00             | 2.00               | 2900 g               | --                    |
| 706                | 24.00 | 8.00  | 8.00  | 4.00               | 4.00              | 30.00              | 10.00            | 10.00            | 2.00               | 2900 g               | 2510                  |
| 707                | 21.00 | 7.00  | 7.00  | -                  | -                 | 39.00              | 13.00            | 13.00            | -                  | 2900 g               | --                    |
| 708                | 21.00 | 7.00  | 7.00  | 2.00               | 2.00              | 36.00              | 12.00            | 12.00            | 1.00               | 2900 g               | --                    |
| 709                | 21.00 | 7.00  | 7.00  | 4.00               | 4.00              | 33.00              | 11.00            | 11.00            | 2.00               | 2900 g               | --                    |
| 710                | 18.00 | 6.00  | 6.00  | -                  | -                 | 42.00              | 14.00            | 14.00            | -                  | 2900 g               | --                    |
| 711                | 18.00 | 6.00  | 6.00  | 2.00               | 2.00              | 39.00              | 13.00            | 13.00            | 1.00               | 2900 g               | --                    |
| 712                | 18.00 | 6.00  | 6.00  | 4.00               | 4.00              | 36.00              | 12.00            | 12.00            | 2.00               | 2900 g               | --                    |

WADC TR 55-290

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>2</sub> O <sub>3</sub> | LiO <sub>0.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|--------------------|-------------------|--------------------|------------------|-------------------------------|--------------------|----------------------|-----------------------|
| 713                | 48.00 | 12.00 | -                  | -                 | 24.00              | 8.00             | 8.00                          | -                  | 2900 d               | --                    |
| 714                | 44.00 | 11.00 | -                  | -                 | 27.00              | 9.00             | 9.00                          | -                  | 2900 d               | --                    |
| 715                | 40.00 | 10.00 | -                  | -                 | 30.00              | 10.00            | 10.00                         | -                  | 2900 g               | 2585                  |
| 716                | 36.00 | 9.00  | -                  | -                 | 33.00              | 11.00            | 11.00                         | -                  | 2900 g               | --                    |
| 717                | 32.00 | 8.00  | -                  | -                 | 36.00              | 12.00            | 12.00                         | -                  | 2900 g               | --                    |
| 718                | 28.00 | 7.00  | -                  | -                 | 39.00              | 13.00            | 13.00                         | -                  | 2900 g               | 2569                  |
| 719                | 44.00 | 11.00 | 2.00               | 2.00              | 24.00              | 8.00             | 8.00                          | 1.00               | 2900 d               | --                    |
| 720                | 40.00 | 10.00 | 2.00               | 2.00              | 27.00              | 9.00             | 9.00                          | 1.00               | 2900 g*              | --                    |
| 721                | 36.00 | 9.00  | 2.00               | 2.00              | 30.00              | 10.00            | 10.00                         | 1.00               | 2900 g               | --                    |
| 722                | 32.00 | 8.00  | 2.00               | 2.00              | 33.00              | 11.00            | 11.00                         | 1.00               | 2900 g               | 2635                  |
| 723                | 28.00 | 7.00  | 2.00               | 2.00              | 36.00              | 12.00            | 12.00                         | 1.00               | 2900 g               | --                    |
| 724                | 24.00 | 6.00  | 2.00               | 2.00              | 39.00              | 13.00            | 13.00                         | 1.00               | 2900 g               | --                    |
| 725                | 40.00 | 10.00 | 4.00               | 4.00              | 24.00              | 8.00             | 8.00                          | 2.00               | 2900 d               | --                    |
| 726                | 36.00 | 9.00  | 4.00               | 4.00              | 27.00              | 9.00             | 9.00                          | 2.00               | 2900 d               | --                    |
| 727                | 32.00 | 8.00  | 4.00               | 4.00              | 30.00              | 10.00            | 10.00                         | 2.00               | 2900 g               | 2342                  |
| 728                | 28.00 | 7.00  | 4.00               | 4.00              | 33.00              | 11.00            | 11.00                         | 2.00               | 2900 g               | --                    |
| 729                | 24.00 | 6.00  | 4.00               | 4.00              | 36.00              | 12.00            | 12.00                         | 2.00               | 2900 g               | --                    |
| 730                | 20.00 | 5.00  | 4.00               | 4.00              | 39.00              | 13.00            | 13.00                         | 2.00               | 2900 g               | 2631                  |
| 731                | 48.00 | 12.00 | -                  | -                 | 24.00              | -                | 16.00                         | -                  | 2900 d               | --                    |
| 732                | 44.00 | 11.00 | -                  | -                 | 27.00              | -                | 18.00                         | -                  | 2900 g               | 2400                  |

WADC TR-55-290

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|--------------------|-------------------|--------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 733                | 40.00 | 10.00 | -                  | -                 | -                  | 30.00              | -                | 20.00            | 2900 g               | --                    |
| 734                | 36.00 | 9.00  | -                  | -                 | -                  | 33.00              | -                | 22.00            | 2900 g               | --                    |
| 735                | 32.00 | 8.00  | -                  | -                 | -                  | 36.00              | -                | 24.00            | 2900 g               | ---                   |
| 736                | 28.00 | 7.00  | -                  | -                 | -                  | 39.00              | -                | 26.00            | 2900 g               | --                    |
| 737                | 24.00 | 6.00  | -                  | -                 | -                  | 42.00              | -                | 28.00            | 2900 g               | 2651                  |
| 738                | 44.00 | 11.00 | 2.00               | 2.00              | 1.00               | 24.00              | -                | 16.00            | 2900 d               | --                    |
| 739                | 40.00 | 10.00 | 2.00               | 2.00              | 1.00               | 27.00              | -                | 18.00            | 2900 g               | --                    |
| 740                | 36.00 | 9.00  | 2.00               | 2.00              | 1.00               | 30.00              | -                | 20.00            | 2900 g               | 2456                  |
| 741                | 32.00 | 8.00  | 2.00               | 2.00              | 1.00               | 33.00              | -                | 22.00            | 2900 g               | --                    |
| 742                | 28.00 | 7.00  | 2.00               | 2.00              | 1.00               | 36.00              | -                | 24.00            | 2900 g               | --                    |
| 743                | 24.00 | 6.00  | 2.00               | 2.00              | 1.00               | 39.00              | -                | 26.00            | 2900 g               | --                    |
| 744                | 20.00 | 5.00  | 2.00               | 2.00              | 1.00               | 42.00              | -                | 28.00            | 2900 g               | --                    |
| 745                | 40.00 | 10.00 | 4.00               | 4.00              | 2.00               | 24.00              | -                | 16.00            | 2900 d               | --                    |
| 746                | 36.00 | 9.00  | 4.00               | 4.00              | 2.00               | 27.00              | -                | 18.00            | 2900 g               | --                    |
| 747                | 32.00 | 8.00  | 4.00               | 4.00              | 2.00               | 30.00              | -                | 20.00            | 2900 g               | 2415                  |
| 748                | 28.00 | 7.00  | 4.00               | 4.00              | 2.00               | 33.00              | -                | 22.00            | 2900 g               | --                    |
| 749                | 24.00 | 6.00  | 4.00               | 4.00              | 2.00               | 36.00              | -                | 24.00            | 2900 g above 2600    |                       |
| 750                | 20.00 | 5.00  | 4.00               | 4.00              | 2.00               | 39.00              | -                | 26.00            | 2900 g               | --                    |
| 751                | 16.00 | 4.00  | 4.00               | 4.00              | 2.00               | 42.00              | -                | 28.00            | 2900 g               | --                    |
| 752                | 48.00 | 12.00 | -                  | -                 | -                  | 24.00              | 16.00            | -                | 2900 d               | --                    |

WADC TR 55-290

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|--------------------|-------------------|--------------------|--------------------|------------------|----------------------|-----------------------|
| 753                | 44.00 | 11.00 | -                  | -                 | -                  | 27.00              | 18.00            | 2900 d               | --                    |
| 754                | 40.00 | 10.00 | -                  | -                 | -                  | 30.00              | 20.00            | 2900 g               | --                    |
| 755                | 36.00 | 9.00  | -                  | -                 | -                  | 33.00              | 22.00            | 2900 g               | --                    |
| 756                | 32.00 | 8.00  | -                  | -                 | -                  | 36.00              | 24.00            | 2900 g               | --                    |
| 757                | 28.00 | 7.00  | -                  | -                 | -                  | 39.00              | 26.00            | 2900 g               | --                    |
| 758                | 24.00 | 6.00  | -                  | -                 | -                  | 42.00              | 28.00            | 2900 g               | --                    |
| 759                | 44.00 | 11.00 | 2.00               | 2.00              | 1.00               | 24.00              | 16.00            | 2900 d               | --                    |
| 760                | 40.00 | 10.00 | 2.00               | 2.00              | 1.00               | 27.00              | 18.00            | 2900 d               | --                    |
| 761                | 36.00 | 9.00  | 2.00               | 2.00              | 1.00               | 30.00              | 20.00            | 2900 g               | --                    |
| 762                | 32.00 | 8.00  | 2.00               | 2.00              | 1.00               | 33.00              | 22.00            | 2900 g               | --                    |
| 763                | 28.00 | 7.00  | 2.00               | 2.00              | 1.00               | 36.00              | 24.00            | 2900 g               | 2625                  |
| 764                | 24.00 | 6.00  | 2.00               | 2.00              | 1.00               | 39.00              | 26.00            | 2900 g               | --                    |
| 765                | 20.00 | 5.00  | 2.00               | 2.00              | 1.00               | 42.00              | 28.00            | 2900 g               | --                    |
| 766                | 40.00 | 10.00 | 4.00               | 4.00              | 2.00               | 24.00              | 16.00            | 2900 d               | --                    |
| 767                | 36.00 | 9.00  | 4.00               | 4.00              | 2.00               | 27.00              | 18.00            | 2900 g               | --                    |
| 768                | 32.00 | 8.00  | 4.00               | 4.00              | 2.00               | 30.00              | 20.00            | 2900 g               | --                    |
| 769                | 28.00 | 7.00  | 4.00               | 4.00              | 2.00               | 33.00              | 22.00            | 2900 g               | 2580                  |
| 770                | 24.00 | 6.00  | 4.00               | 4.00              | 2.00               | 36.00              | 24.00            | 2900 g               | --                    |
| 771                | 20.00 | 5.00  | 4.00               | 4.00              | 2.00               | 39.00              | 26.00            | 2900 g               | --                    |
| 772                | 16.00 | 4.00  | 4.00               | 4.00              | 2.00               | 42.00              | 28.00            | 2900 g               | --                    |

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINUM GLASSES

| Composition<br>No. | CaO   | MgO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|--------------------|-------------------|--------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 773                | 44.00 | 11.00 | 1.00               | 2.00              | 2.00               | 24.00              | 8.00             | 8.00             | 2900 d               | --                    |
| 774                | 40.00 | 10.00 | 1.00               | 2.00              | 2.00               | 27.00              | 9.00             | 9.00             | 2900 d               | --                    |
| 775                | 36.00 | 9.00  | 1.00               | 2.00              | 2.00               | 30.00              | 10.00            | 10.00            | 2900 g               | 2475                  |
| 776                | 32.00 | 8.00  | 1.00               | 2.00              | 2.00               | 33.00              | 11.00            | 11.00            | 2900 g               | --                    |
| 777                | 28.00 | 7.00  | 1.00               | 2.00              | 2.00               | 36.00              | 12.00            | 12.00            | 2900 g               | --                    |
| 778                | 24.00 | 6.00  | 1.00               | 2.00              | 2.00               | 39.00              | 13.00            | 13.00            | 2900 g               | --                    |
| 779                | 20.00 | 5.00  | 1.00               | 2.00              | 2.00               | 42.00              | 14.00            | 14.00            | 2900 g               | --                    |
| 780                | 40.00 | 10.00 | 2.00               | 4.00              | 4.00               | 24.00              | 8.00             | 8.00             | 2900 d               | --                    |
| 781                | 36.00 | 9.00  | 2.00               | 4.00              | 4.00               | 27.00              | 9.00             | 9.00             | 2900 d               | --                    |
| 782                | 32.00 | 8.00  | 2.00               | 4.00              | 4.00               | 30.00              | 10.00            | 10.00            | 2900 g               | --                    |
| 783                | 28.00 | 7.00  | 2.00               | 4.00              | 4.00               | 33.00              | 11.00            | 11.00            | 2900 g               | 2538                  |
| 784                | 24.00 | 6.00  | 2.00               | 4.00              | 4.00               | 36.00              | 12.00            | 12.00            | 2900 g               | --                    |
| 785                | 20.00 | 5.00  | 2.00               | 4.00              | 4.00               | 39.00              | 13.00            | 13.00            | 2900 g               | --                    |
| 786                | 16.00 | 4.00  | 2.00               | 4.00              | 4.00               | 42.00              | 14.00            | 14.00            | 2900 g               | --                    |
| 787                | 36.00 | 9.00  | 3.00               | 6.00              | 6.00               | 24.00              | 8.00             | 8.00             | 2900 d               | --                    |
| 788                | 32.00 | 8.00  | 3.00               | 6.00              | 6.00               | 27.00              | 9.00             | 9.00             | 2900 d               | --                    |
| 789                | 28.00 | 7.00  | 3.00               | 6.00              | 6.00               | 30.00              | 10.00            | 10.00            | 2900 g               | 2200                  |
| 790                | 24.00 | 6.00  | 3.00               | 6.00              | 6.00               | 33.00              | 11.00            | 11.00            | 2900 g               | --                    |
| 791                | 20.00 | 5.00  | 3.00               | 6.00              | 6.00               | 36.00              | 12.00            | 12.00            | 2900 g               | ---                   |
| 792                | 16.00 | 4.00  | 3.00               | 6.00              | 6.00               | 39.00              | 13.00            | 13.00            | 2900 g               | --                    |

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO   | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-------|--------------------|-------------------|--------------------|--------------------|------------------|------------------|----------------------|-----------------------|
| 793                | 44.00 | 11.00 | 2.00               | 1.00              | 2.00               | 24.00              | 8.00             | 8.00             | 2900 d               | --                    |
| 794                | 40.00 | 10.00 | 2.00               | 1.00              | 2.00               | 27.00              | 9.00             | 9.00             | 2900 g               | 2376                  |
| 795                | 36.00 | 9.00  | 2.00               | 1.00              | 2.00               | 30.00              | 10.00            | 10.00            | 2900 g               | --                    |
| 796                | 32.00 | 8.00  | 2.00               | 1.00              | 2.00               | 33.00              | 11.00            | 11.00            | 2900 g               | 2525                  |
| 797                | 28.00 | 7.00  | 2.00               | 1.00              | 2.00               | 36.00              | 12.00            | 12.00            | 2900 g               | --                    |
| 798                | 24.00 | 6.00  | 2.00               | 1.00              | 2.00               | 39.00              | 13.00            | 13.00            | 2900 g               | --                    |
| 799                | 20.00 | 5.00  | 2.00               | 1.00              | 2.00               | 42.00              | 14.00            | 14.00            | 2900 g               | --                    |
| 800                | 40.00 | 10.00 | 4.00               | 2.00              | 4.00               | 24.00              | 8.00             | 8.00             | 2900 d               | --                    |
| 801                | 36.00 | 9.00  | 4.00               | 2.00              | 4.00               | 27.00              | 9.00             | 9.00             | 2900 g               | --                    |
| 802                | 32.00 | 8.00  | 4.00               | 2.00              | 4.00               | 30.00              | 10.00            | 10.00            | 2900 g               | 2600                  |
| 803                | 28.00 | 7.00  | 4.00               | 2.00              | 4.00               | 33.00              | 11.00            | 11.00            | 2900 g               | --                    |
| 804                | 24.00 | 6.00  | 4.00               | 2.00              | 4.00               | 36.00              | 12.00            | 12.00            | 2900 g               | --                    |
| 805                | 20.00 | 5.00  | 4.00               | 2.00              | 4.00               | 39.00              | 13.00            | 13.00            | 2900 g               | --                    |
| 806                | 16.00 | 4.00  | 4.00               | 2.00              | 4.00               | 42.00              | 14.00            | 14.00            | 2900 g               | --                    |
| 807                | 36.00 | 9.00  | 6.00               | 3.00              | 6.00               | 24.00              | 8.00             | 8.00             | 2900 d               | --                    |
| 808                | 32.00 | 8.00  | 6.00               | 3.00              | 6.00               | 27.00              | 9.00             | 9.00             | 2900 d               | --                    |
| 809                | 28.00 | 7.00  | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 10.00            | 2900 g               | 2500                  |
| 810                | 24.00 | 6.00  | 6.00               | 3.00              | 6.00               | 33.00              | 11.00            | 11.00            | 2900 g               | --                    |
| 811                | 20.00 | 5.00  | 6.00               | 3.00              | 6.00               | 36.00              | 12.00            | 12.00            | 2900 g               | --                    |
| 812                | 16.00 | 4.00  | 6.00               | 3.00              | 6.00               | 39.00              | 13.00            | 13.00            | 2900 g               | --                    |

WADC TR 55-290

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | BaO   | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|-----|--------------------|-------------------|--------------------|--------------------|------------------|------------------|-------|----------------------|-----------------------|
| 813                | 48.00 | -   | -                  | -                 | -                  | 24.00              | 8.00             | 8.00             | 12.00 | 2900 d               | --                    |
| 814                | 44.00 | -   | -                  | -                 | -                  | 27.00              | 9.00             | 9.00             | 11.00 | 2900 g               | --                    |
| 815                | 40.00 | -   | -                  | -                 | -                  | 30.00              | 10.00            | 10.00            | 10.00 | 2900 g               | --                    |
| 816                | 36.00 | -   | -                  | -                 | -                  | 33.00              | 11.00            | 11.00            | 9.00  | 2900 g               | --                    |
| 817                | 32.00 | -   | -                  | -                 | -                  | 36.00              | 12.00            | 12.00            | 8.00  | 2900 g               | --                    |
| 818                | 28.00 | -   | -                  | -                 | -                  | 39.00              | 13.00            | 13.00            | 7.00  | 2900 g               | --                    |
| 819                | 24.00 | -   | -                  | -                 | -                  | 42.00              | 14.00            | 14.00            | 6.00  | 2900 g               | --                    |
| 820                | 44.00 | -   | 2.00               | 2.00              | 1.00               | 24.00              | 8.00             | 8.00             | 11.00 | 2900 d               | --                    |
| 821                | 40.00 | -   | 2.00               | 2.00              | 1.00               | 27.00              | 9.00             | 9.00             | 10.00 | 2900 d               | --                    |
| 822                | 36.00 | -   | 2.00               | 2.00              | 1.00               | 30.00              | 10.00            | 10.00            | 9.00  | 2900 g               | --                    |
| 823                | 32.00 | -   | 2.00               | 2.00              | 1.00               | 33.00              | 11.00            | 11.00            | 8.00  | 2900 g               | --                    |
| 824                | 28.00 | -   | 2.00               | 2.00              | 1.00               | 36.00              | 12.00            | 12.00            | 7.00  | 2900 g               | --                    |
| 825                | 24.00 | -   | 2.00               | 2.00              | 1.00               | 39.00              | 13.00            | 13.00            | 6.00  | 2900 g               | --                    |
| 826                | 20.00 | -   | 2.00               | 2.00              | 1.00               | 42.00              | 14.00            | 14.00            | 5.00  | 2900 g               | --                    |
| 827                | 40.00 | -   | 4.00               | 4.00              | 2.00               | 24.00              | 8.00             | 8.00             | 10.00 | 2900 d               | --                    |
| 828                | 36.00 | -   | 4.00               | 4.00              | 2.00               | 27.00              | 9.00             | 9.00             | 9.00  | 2900 d               | --                    |
| 829                | 32.00 | -   | 4.00               | 4.00              | 2.00               | 30.00              | 10.00            | 10.00            | 8.00  | 2900 g               | --                    |
| 830                | 28.00 | -   | 4.00               | 4.00              | 2.00               | 33.00              | 11.00            | 11.00            | 7.00  | 2900 g               | --                    |
| 831                | 24.00 | -   | 4.00               | 4.00              | 2.00               | 36.00              | 12.00            | 12.00            | 6.00  | 2900 g               | --                    |
| 832                | 20.00 | -   | 4.00               | 4.00              | 2.00               | 39.00              | 13.00            | 13.00            | 5.00  | 2900 g               | --                    |
| 833                | 16.00 | -   | 4.00               | 4.00              | 2.00               | 42.00              | 14.00            | 14.00            | 4.00  | 2900 g               | --                    |

WADC TR 55-290

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | FeO <sub>1.5</sub> | Melting<br>Temp., °F. | Liquidus<br>Temp., °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|--------------------|------------------|------------------|--------------------|-----------------------|------------------------|
| 852                | 30.00 | 5.00 | -    | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 10.00            | -                  | 2900 g                | 2345                   |
| 853                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 10.00            | -                  | 2900 g                | 2315                   |
| 854                | 28.00 | 7.00 | -    | 3.00               | 3.00              | 9.00               | 30.00              | 10.00            | 10.00            | -                  | 2900 g                | 2630                   |
| 855                | 28.00 | 7.00 | -    | 9.00               | 3.00              | 3.00               | 30.00              | 10.00            | 10.00            | -                  | 2900 g                | 2655                   |
| 856                | 28.00 | 7.00 | -    | 6.00               | -                 | 9.00               | 30.00              | 10.00            | 10.00            | -                  | 2900 g                | 2600                   |
| 857                | 28.00 | 7.00 | -    | -                  | 6.00              | 9.00               | 30.00              | 10.00            | 10.00            | -                  | 2900 g                | 2600                   |
| 858                | 28.00 | 7.00 | -    | 6.00               | 3.00              | 6.00               | 33.00              | 7.00             | 10.00            | -                  | 2900 g                | 2600                   |
| 859                | 28.00 | 7.00 | -    | 6.00               | 3.00              | 6.00               | 30.00              | 7.00             | 13.00            | -                  | 2900 g                | 2450                   |
| 860                | 28.00 | 7.00 | -    | 6.00               | 3.00              | 6.00               | 33.50              | -                | 16.50            | -                  | 2900 g                | 2390                   |
| 861                | 28.00 | 7.00 | -    | 6.00               | 3.00              | 6.00               | 40.00              | -                | 10.00            | -                  | 2900 g                | -                      |
| 862                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 51.05              | -                | -                | 5.67               | 2900 d                | -                      |
| 863                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 45.38              | -                | -                | 11.34              | 2900 d                | -                      |
| 864                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 39.70              | -                | -                | 17.02              | 2900 d                | -                      |
| 865                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 45.38              | -                | 5.67             | 5.67               | 2900 d                | -                      |
| 866                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 39.70              | -                | 5.67             | 11.34              | 2900 d                | -                      |
| 867                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 34.03              | -                | 5.67             | 17.02              | 2900 d                | -                      |
| 868                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 39.70              | -                | 11.34            | 5.67               | 2900 d                | -                      |
| 869                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 34.03              | -                | 11.34            | 11.34              | 2900 d                | -                      |
| 870                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 34.03              | -                | 17.02            | 5.67               | 2900 d                | -                      |
| 871                | 27.54 | 5.16 | 1.72 | 5.85               | 3.00              | -                  | 28.36              | -                | 17.02            | 11.34              | 2900 d                | -                      |

WADC 1 TR 55-290

54

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | FeO <sub>1.5</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|--------------------|-------------------|--------------------|--------------------|------------------|------------------|--------------------|----------------------|-----------------------|
| WAD 872            | 24.00 | 6.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 10.00            | 5.00               | 2900 d               | --                    |
| 873                | 20.00 | 5.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 10.00            | 10.00              | 2900 d               | --                    |
| TR 874             | 16.00 | 4.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 10.00            | 15.00              | 2900 d               | --                    |
| 55-290 875         | 12.00 | 3.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 10.00            | 20.00              | 2900 d               | --                    |
| 876                | 24.00 | 6.00 | 6.00               | 3.00              | 6.00               | 35.00              | 7.50             | 7.50             | 5.00               | 2900 d               | --                    |
| 877                | 20.00 | 5.00 | 6.00               | 3.00              | 6.00               | 35.00              | 7.50             | 7.50             | 10.00              | 2900 d               | --                    |
| 878                | 16.00 | 4.00 | 6.00               | 3.00              | 6.00               | 35.00              | 7.50             | 7.50             | 15.00              | 2900 d               | --                    |
| 879                | 12.00 | 3.00 | 6.00               | 3.00              | 6.00               | 35.00              | 7.50             | 7.50             | 20.00              | 2900 d               | --                    |
| 5 880              | 24.00 | 6.00 | 6.00               | 3.00              | 6.00               | 40.00              | 5.00             | 5.00             | 5.00               | 2900 d               | --                    |
| 881                | 20.00 | 5.00 | 6.00               | 3.00              | 6.00               | 40.00              | 5.00             | 5.00             | 10.00              | 2900 d               | --                    |
| 882                | 16.00 | 4.00 | 6.00               | 3.00              | 6.00               | 40.00              | 5.00             | 5.00             | 15.00              | 2900 d               | --                    |
| 883                | 12.00 | 3.00 | 6.00               | 3.00              | 6.00               | 40.00              | 5.00             | 5.00             | 20.00              | 2900 d               | --                    |
| 884                | 24.00 | 6.00 | 6.00               | 3.00              | 6.00               | 45.00              | 2.50             | 2.50             | 5.00               | 2900 d               | --                    |
| 885                | 20.00 | 5.00 | 6.00               | 3.00              | 6.00               | 45.00              | 2.50             | 2.50             | 10.00              | 2900 d               | --                    |
| 886                | 16.00 | 4.00 | 6.00               | 3.00              | 6.00               | 45.00              | 2.50             | 2.50             | 15.00              | 2900 d               | --                    |
| 887                | 12.00 | 3.00 | 6.00               | 3.00              | 6.00               | 45.00              | 2.50             | 2.50             | 20.00              | 2900 d               | --                    |
| 888                | 24.00 | 6.00 | 6.00               | 3.00              | 6.00               | 50.00              | -                | -                | 5.00               | 2900 d               | --                    |
| 889                | 20.00 | 5.00 | 6.00               | 3.00              | 6.00               | 50.00              | -                | -                | 10.00              | 2900 d               | --                    |
| 890                | 16.00 | 4.00 | 6.00               | 3.00              | 6.00               | 50.00              | -                | -                | 15.00              | 2900 d               | --                    |
| 891                | 12.00 | 3.00 | 6.00               | 3.00              | 6.00               | 50.00              | -                | -                | 20.00              | 2900 d               | --                    |

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|--------------------|------------------|------------------|------------------|------------------|----------------------|-----------------------|
| 892                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 8.00             | 8.00             | -                | 2900 d               | --                    |
| 893                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 6.00             | 4.00             | -                | 2900 d               | --                    |
| 894                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 4.00             | 6.00             | -                | 2900 s               | --                    |
| 895                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 2.00             | 8.00             | -                | 2900 s               | --                    |
| 896                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | -                | 10.00            | -                | 2900 s               | --                    |
| 897                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 8.00             | -                | 2.00             | 2900 d               | --                    |
| 898                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 6.00             | 2.00             | 2.00             | 2900 d               | 2560                  |
| 899                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 4.00             | 4.00             | 2.00             | 2900 d               | --                    |
| 900                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 2.00             | 6.00             | 2.00             | 2900 d               | --                    |
| 901                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | -                | 8.00             | 4.00             | 2900 d               | --                    |
| 902                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 6.00             | -                | 4.00             | 2900 d               | --                    |
| 903                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 4.00             | 2.00             | 4.00             | 2900 d               | --                    |
| 904                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 2.00             | 4.00             | 4.00             | 2900 d               | --                    |
| 905                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | -                | 6.00             | 4.00             | 2900 d               | --                    |
| 906                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 4.00             | -                | 6.00             | 2900 s               | --                    |
| 907                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 2.00             | 2.00             | 6.00             | 2900 s               | --                    |
| 908                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | -                | 4.00             | 6.00             | 2900 s               | --                    |
| 909                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 2.00             | -                | 8.00             | 2900 s               | --                    |
| 910                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | -                | 2.00             | 8.00             | 2900 s               | --                    |
| 911                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | -                | -                | 10.00            | 2900 s               | --                    |

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|--------------------|------------------|-------------------------------|------------------|------------------|----------------------|-----------------------|
| 912                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 8.00             | 10.00                         | 2.00             | -                | 2900 d               | --                    |
| 913                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 6.00             | 10.00                         | 4.00             | -                | 2900 d               | --                    |
| 914                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 4.00             | 10.00                         | 6.00             | -                | 2900 d               | --                    |
| 915                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 2.00             | 10.00                         | 8.00             | -                | 2900 d               | --                    |
| 916                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | -                | 10.00                         | 10.00            | -                | 2900 d               | --                    |
| 917                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 6.00             | 10.00                         | 2.00             | 2.00             | 2900 d               | 2530                  |
| 918                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 4.00             | 10.00                         | 4.00             | 2.00             | 2900 d               | --                    |
| 919                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 6.00             | 10.00                         | -                | 4.00             | 2900 s               | --                    |
| 920                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 4.00             | 10.00                         | 2.00             | 4.00             | 2900 s               | --                    |
| 921                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 2.00             | 10.00                         | 2.00             | 6.00             | 2900 s               | --                    |
| 922                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 9.00             | 9.00                          | 2.00             | -                | 2900 d               | 2375                  |
| 923                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 8.00             | 8.00                          | 2.00             | 2.00             | 2900 d               | 2530                  |
| 924                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 7.00             | 7.00                          | 4.00             | 2.00             | 2900 d               | --                    |
| 925                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 6.00             | 6.00                          | 4.00             | 4.00             | 2900 d               | --                    |
| 926                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 28.00              | 10.00            | 10.00                         | 2.00             | -                | 2900 d               | --                    |
| 927                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 26.00              | 10.00            | 10.00                         | 4.00             | -                | 2900 d               | 2480                  |
| 928                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 24.00              | 10.00            | 10.00                         | 6.00             | -                | 2900 d               | --                    |
| 929                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 22.00              | 10.00            | 10.00                         | 8.00             | -                | 2900 d               | --                    |
| 930                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 20.00              | 10.00            | 10.00                         | 10.00            | -                | 2900 d               | --                    |
| 931                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 26.00              | 10.00            | 10.00                         | 2.00             | 2.00             | 2900 d               | --                    |

WADC TR 55-290

TABLE III (Cont.)  
SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

| Composition<br>No. | CaO   | MgO  | BaO  | NaO <sub>0.5</sub> | KO <sub>0.5</sub> | LiO <sub>0.5</sub> | AlO <sub>1.5</sub> | SiO <sub>2</sub> | B <sub>0.5</sub> | TiO <sub>2</sub> | ZrO <sub>2</sub> | Melting<br>Temp. °F. | Liquidus<br>Temp. °F. |
|--------------------|-------|------|------|--------------------|-------------------|--------------------|--------------------|------------------|------------------|------------------|------------------|----------------------|-----------------------|
| 932                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 24.00              | 10.00            | 10.00            | 4.00             | 2.00             | 2900 d               | ---                   |
| 933                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 24.00              | 10.00            | 10.00            | 2.00             | 4.00             | 2900 s               | ---                   |
| 934                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 22.00              | 10.00            | 10.00            | 2.00             | 6.00             | 2900 s               | ---                   |
| 935                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 28.00              | 9.00             | 9.00             | 2.00             | 2.00             | 2900 d               | 2510                  |
| 936                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 28.00              | 8.00             | 8.00             | 4.00             | 2.00             | 2900 d above 2600    |                       |
| 937                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 26.00              | 8.00             | 8.00             | 4.00             | 4.00             | 2900 s               | ---                   |
| 938                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 26.00              | 8.00             | 8.00             | 2.00             | 6.00             | 2900 s               | ---                   |
| 939                | 28.00 | 5.00 | 2.00 | 6.00               | 3.00              | 6.00               | 26.00              | 8.00             | 8.00             | 6.00             | 2.00             | 2900 d               | ---                   |
| 940                | 30.00 | 3.00 | 2.00 | 6.00               | 3.00              | 6.00               | 30.00              | 10.00            | 6.00             | 2.00             | 2.00             | 2900 d               | 2550                  |
| 941                | 30.00 | 3.00 | 2.00 | 9.00               | 3.00              | 3.00               | 30.00              | 10.00            | 6.00             | 2.00             | 2.00             | 2900 d               | 2565                  |
| 942                | 30.00 | 3.00 | 2.00 | 6.00               | 6.00              | 3.00               | 30.00              | 10.00            | 6.00             | 2.00             | 2.00             | 2900 d               | 2565                  |
| 943                | 28.00 | 4.00 | 3.00 | 6.00               | 6.00              | 3.00               | 30.00              | 10.00            | 6.00             | 2.00             | 2.00             | 2900 d               | 2550                  |
| 944                | 28.00 | 3.00 | 2.00 | 6.00               | 6.00              | 3.00               | 32.00              | 10.00            | 6.00             | 2.00             | 2.00             | 2900 d               | 2535                  |
| 945                | 28.00 | 3.00 | 2.00 | 5.00               | 3.00              | 3.00               | 32.00              | 10.00            | 8.00             | 2.00             | 2.00             | 2900 d               | 2485                  |
| 946                | 28.00 | 3.00 | 2.00 | 9.00               | 5.00              | 3.00               | 30.00              | 10.00            | 6.00             | 2.00             | 2.00             | 2900 d               | 2560                  |
| 947                | 28.00 | 3.00 | 2.00 | 11.00              | 3.00              | 3.00               | 30.00              | 10.00            | 6.00             | 2.00             | 2.00             | 2900 d               | 2600                  |
| 948                | 28.00 | 3.00 | 2.00 | 6.00               | 6.00              | 3.00               | 30.00              | 10.00            | 8.00             | 2.00             | 2.00             | 2900 d               | 2600                  |
| 949                | 32.00 | 3.00 | 2.00 | 6.00               | 6.00              | 3.00               | 30.00              | 10.00            | 4.00             | 2.00             | 2.00             | 2900 d               | 2590                  |

TABLE IV.

## PHYSICAL PROPERTIES OF CALCIUM ALUMINATE GLASSES

| Glass No.      | log. viscosity in poises |             |             |                      |             | Specific Gravity<br>gm/ml | Ex10 <sup>-6</sup><br>psi | Specific Modulus<br>psi/lb./cu.ft.<br>x10 <sup>-4</sup> |
|----------------|--------------------------|-------------|-------------|----------------------|-------------|---------------------------|---------------------------|---------------------------------------------------------|
|                | 0.5<br>°F.               | 0.75<br>°F. | 1.00<br>°F. | 1.25<br>°F.          | 1.50<br>°F. |                           |                           |                                                         |
| Std.<br>WAD632 | --                       | --          | --          | --                   | 2650        | 2.59                      | 11.95                     | 7.39                                                    |
| 632            | --                       | --          | --          | 2610                 | 2515        | 2.90                      | 15.0                      | 8.29                                                    |
| 633            | --                       | --          | --          | 2700 devitrification | --          | 3.00                      | 16.3                      | 8.39                                                    |
| 5638           | --                       | --          | --          | 2615                 | 2530        | 2.83                      | 15.45                     | 8.74                                                    |
| 639            | --                       | --          | --          | 2655                 | 2565        | 3.09                      | 15.10                     | 7.83                                                    |
| 5639           | --                       | --          | --          | 2630                 | 2535        | 2.90                      | 15.25                     | 8.43                                                    |
| 653            | --                       | --          | --          | 2635                 | 2530        | 2.88                      | 14.28                     | 7.94                                                    |
| 656            | --                       | --          | 2750        | 2535                 | 2455        | 2.90                      | 15.52                     | 8.57                                                    |
| 657            | --                       | 2755        | 2640        | 2535                 | 2485        | 2.91                      | 15.41                     | 8.48                                                    |
| 5659           | --                       | 2720        | 2595        | 2485                 | --          | 2.88                      | --                        | --                                                      |
| 661            | --                       | 2740        | 2615        | 2505                 | 2415        | 2.89                      | --                        | --                                                      |
| 662            | --                       | 2575        | 2460        | 2360                 | --          | 2.89                      | 14.63                     | 8.11                                                    |
| 664            | --                       | --          | --          | --                   | --          | 2.89                      | --                        | --                                                      |
| 666            | 2650                     | 2475        | 2330        | 2220                 | 2140        | 2.87                      | 14.60                     | 8.15                                                    |
| 670            | 2430                     | 2305        | 2195        | 2100                 | 2020        | 2.85                      | 13.44                     | 7.55                                                    |
| 672            | --                       | --          | 2650        | 2555                 | 2480        | 2.91                      | 15.68                     | 8.63                                                    |
| 675            | --                       | --          | 2685        | 2610                 | 2535        | 2.89                      | 15.16                     | 8.40                                                    |
| 677            | --                       | --          | --          | 2665                 | 2565        | 2.88                      | 14.75                     | 8.19                                                    |
| 683            | --                       | --          | 2610        | 2495                 | --          | 2.92                      | 15.85                     | 8.69                                                    |
| 686            | --                       | --          | 2640        | 2510                 | 2400        | 2.90                      | 15.42                     | 8.52                                                    |
| 688            | --                       | --          | --          | --                   | --          | 2.91                      | 15.90                     | 8.75                                                    |

TABLE IV. (Cont.)

## PHYSICAL PROPERTIES OF CALCIUM ALUMINATE GLASSES

| Glass No. | log. viscosity in poises |             |             |             |             | Specific Gravity<br>gm/ml | Ex 10 <sup>-6</sup><br>psi | Specific Modulus<br>psi/lb/cu. ft.<br>x 10 <sup>-4</sup> |
|-----------|--------------------------|-------------|-------------|-------------|-------------|---------------------------|----------------------------|----------------------------------------------------------|
|           | 0.5<br>°F.               | 0.75<br>°F. | 1.00<br>°F. | 1.25<br>°F. | 1.50<br>°F. | 1.75<br>°F.               |                            |                                                          |
| 692       | --                       | 2615        | 2510        | 2415        | --          | 2.92                      | 16.20                      | 8.89                                                     |
| 695       | 2595                     | --          | --          | --          | --          | 3.28                      | 14.27                      | 6.97                                                     |
| 702       | 2750                     | 2595        | 2470        | 2385        | 2315        | 3.16                      | 14.78                      | 7.49                                                     |
| 706       | 2735                     | 2570        | 2450        | --          | --          | 3.14                      | 12.60                      | 6.43                                                     |
| 715       | --                       | 2615        | 2495        | 2390        | 2300        | 2.92                      | 15.69                      | 8.61                                                     |
| 718       | 2715                     | 2605        | 2495        | 2385        | --          | 2.83                      | 14.65                      | 8.29                                                     |
| 722       | 2695                     | 2550        | 2430        | 2350        | --          | 2.84                      | 14.79                      | 8.34                                                     |
| 727       | 2690                     | 2555        | 2430        | 2355        | --          | 2.84                      | 15.19                      | 8.56                                                     |
| 730       | --                       | 2705        | 2590        | 2495        | 2410        | 2.72                      | 14.06                      | 8.28                                                     |
| 732       | 2475                     | 2390        | --          | --          | --          | 2.91                      | --                         | --                                                       |
| 737       | --                       | --          | --          | 2700        | 2620        | --                        | --                         | --                                                       |
| 740       | 2345                     | 2215        | 2100        | --          | --          | 2.86                      | --                         | --                                                       |
| 763       | --                       | --          | 2605        | --          | --          | 2.83                      | 15.04                      | 8.51                                                     |
| 769       | --                       | --          | 2630        | 2510        | 2410        | 2.81                      | 14.81                      | 8.44                                                     |
| 775       | --                       | --          | 2390        | 2290        | 2220        | 2.87                      | 15.3                       | 8.54                                                     |
| 783       | 2475                     | 2350        | --          | --          | --          | 2.80                      | 14.8                       | 8.46                                                     |
| 789       | 2600                     | 2430        | 2310        | 2215        | 2130        | 2.79                      | 15.0                       | 8.61                                                     |
| 794       | 2474                     | 2350        | --          | --          | --          | 2.90                      | 15.37                      | 8.49                                                     |
| 796       | --                       | 2445        | 2355        | --          | --          | 2.85                      | 15.20                      | 8.54                                                     |
| 802       | 2620                     | 2475        | --          | --          | --          | 2.87                      | 15.28                      | 8.53                                                     |

WADC TR 55-290

60

TABLE IV. (Cont.)

## PHYSICAL PROPERTIES OF CALCIUM ALUMINATE GLASSES

| Glass No. | log. viscosity in poises |             |             |             |             | Specific Gravity<br>gm/ml | Ex $10^{-6}$<br>psi | Specific Modulus<br>psi/lb/cu.ft.<br>$\times 10^{-4}$ |
|-----------|--------------------------|-------------|-------------|-------------|-------------|---------------------------|---------------------|-------------------------------------------------------|
|           | 0.5<br>°F.               | 0.75<br>°F. | 1.00<br>°F. | 1.25<br>°F. | 1.50<br>°F. | 1.75<br>°F.               |                     |                                                       |
| 809       | 2570                     | 2430        | 2305        | 2195        | 2100        | 2020                      | 15.15               | 8.67                                                  |
| 852       | 2570                     | 2430        | 2305        | 2195        | 2100        | 2020                      | 15.10               | 8.61                                                  |
| 853       | 2595                     | 2430        | 2305        | 2205        | 2115        | 2035                      | 15.20               | 8.43                                                  |
| 854       | 2530                     | 2370        | 2250        | 2150        | 2075        | 2000                      | 15.36               | 8.76                                                  |
| 855       | 2600                     | 2445        | 2320        | 2215        | 2125        | 2050                      | 15.0                | 8.55                                                  |
| 856       | --                       | 2524        | 2260        | 2125        | 2025        | 1940                      | 13.8                | 7.89                                                  |
| 857       | 2560                     | 2435        | 2315        | 2210        | 2120        | 2040                      | --                  | --                                                    |
| 858       | 2580                     | 2445        | 2315        | 2200        | 2100        | 2005                      | --                  | --                                                    |
| 859       | --                       | 2360        | 2215        | 2120        | 2035        | 1970                      | --                  | --                                                    |
| 860       | 2505                     | 2345        | 2225        | 2125        | 2025        | --                        | 13.94               | 8.00                                                  |
| 898       | 2555                     | 2420        | 2310        | 2230        | 2155        | 2090                      | 15.30               | 8.25                                                  |
| 940       | 2575                     | 2430        | 2325        | 2245        | 2175        | 2115                      | 14.74               | 8.06                                                  |
| 941       | --                       | 2470        | 2335        | 2245        | 2175        | 2120                      | 16.23               | 8.73                                                  |
| 942       | 2520                     | 2435        | 2365        | 2300        | --          | --                        | 16.24               | 8.73                                                  |
| 945       | --                       | 2490        | 2375        | 2285        | 2205        | 2130                      | 15.00               | 8.09                                                  |
| 946       | 2585                     | 2450        | 2350        | 2290        | 2200        | 2130                      | 14.81               | 7.99                                                  |
| 947       | 2580                     | 2455        | 2365        | 2285        | --          | --                        | 14.97               | 8.05                                                  |
| 949       | --                       | 2480        | 2375        | --          | --          | --                        | 15.25               | 8.14                                                  |

The results of this compositional study with regards to the elastic modulus of the annealed calcium aluminate type glass and the viscosity of the melt as a function of the composition were as follows:

1. The substitution of silicon or boron for aluminum decreases Young's modulus.
2. The substitution of barium for calcium decreases Young's modulus.
3. The substitution of magnesium for calcium increases Young's modulus.
4. The substitution of potassium for sodium decreases Young's modulus.
5. The substitution of lithium for sodium increases Young's modulus.
6. The substitution of alkali ions or aluminum, silicon and boron for alkaline earth ion decreases Young's modulus.
7. The substitution of barium or magnesium for calcium increases the viscosity of the melt.
8. The substitution of potassium for sodium increases the viscosity of the melt.
9. The substitution of lithium for sodium decreases the viscosity of the melt.
10. The substitution of silicon for aluminum increases the viscosity of the melt only slightly.
11. The substitution of boron for aluminum greatly decreases the viscosity of the melt.

No general rule could be formulated with regards to liquidus temperatures. No satisfactory glasses were found which contained more than two or three cation percent of titania, zirconia, iron, manganese, or copper oxides. Figure 2 represents the Young's modulus data listed in Table III. The glasses have been grouped together to show the effects of the substitution of one ion for another.

Compositions Nos. 632, 633, 638 and 639 differ only in relative amounts of Ca ions, Ba ions and Mg ions in the total alkaline earth present in the glass. All other components have been kept at a constant ion percent.

No. 632 contains all of the alkaline earth ions as Ca ions.

In No. 633, 20% of the Ca ions have been replaced by Ba ions.

In No. 638, 20% of the Ca ions have been replaced by Mg ions.

In No. 639, 20% of the Ca ions have been replaced by Ba ions and 20% by Mg ions.

Compositions Nos. 715, 695, 722, 727 and 706 are examples of the replacement of Ca ions by Ba ions. These glasses are not comparable to any other glass except the one to which they are paired on the chart, because all others contain variations in other components as well as Ca ions and Ba ions. In each pair, the second glass was identical to the first except for the replacement of 20% of the Ca ions by Ba ions.

Evaluation of this information on the replacement of Ca ions by Ba ions and Mg ions, as it affects Young's modulus, leads to these conclusions:

1. The replacement of Ca ions by Ba ions usually decreases Young's modulus.
2. The replacement of Ca ions by Mg ions increases Young's modulus.

In Figure 2, Compositions Nos. 692, 683, 686 and 688 differ only in the relative amounts of Li ions, Na ions and K ions in the total alkali ions present. All other components were kept at a constant ion percent.

Composition No. 692 contains all of the alkali ions as Li ions.

In No. 683, 60% of the Li ions have been replaced by Na ions.

In No. 686, 60% of the Li ions have been replaced by K ions.

In No. 688, 20% of the Li ions have been replaced by Na ions and 20% by K ions.

Evaluation of this data on the effect of the relative amounts of each of the alkali ions present on Young's modulus leads to the following conclusions:

1. The replacement of Li ions by Na ions decreases Young's modulus.
2. The replacement of Li ions by K ions decreases Young's modulus.
3. The replacement of Na ions by K ions decreases Young's modulus.

In Figure 2, Compositions Nos. 395, 653, 657 and 659 differ only in the relative amounts of Al ions, Si ions and B ions present in the composition. All other components remain constant.

Composition 395 contains only Al ions.

In No. 653, 20% of the Al ions are replaced by Si ions.

In No. 656, 50% of the Al ions are replaced by Si ions.

In No. 657, 10% of the Al ions are replaced by B ions.

In No. 659, 30% of the Al ions are replaced by Si ions and 10% by B ions.

The conclusion from this data is:

1. The replacement of Al ions by either Si ions or B ions decreases Young's modulus.

The effect of the substitution of alkaline earth ions for alkali ions can be seen by comparing No. 715 and No. 727 in Figure 2. No. 715 is different from No. 727 only in the replacement of 10% of the total alkaline earth ions by alkali ions on an ion for ion basis. No. 715 contains no alkali ions. This same observation can be seen in the comparison of No. 695 and No. 706. No. 706 contains 10% alkali ions which have been substituted for alkaline earth ions.

The effect of the substitution of alkaline earth ions for Al, Si and B ions can be seen by comparing No. 715 and No. 718. No. 718 is not in Figure 2 but is listed in Table III. No. 715 was identical to No. 718 except for the replacement of 15% of the Al, Si and B ions of No. 718 by alkaline earth ions. The alkali ions and the relative quantities of Al ions, Si ions and B ions were held constant.

The above comparisons lead to the conclusion that:

1. The substitution of alkali ions for alkaline earth ions decreases Young's modulus.
2. The substitution of Al, Si and B ions for alkaline earth ions decreases Young's modulus.

The effect of the substitution of alkali ions for Al, Si and B ions can be seen by comparing No. 706 and No. 702. No. 706 was identical to No. 702 except for the replacement of 5% of the Al, Si and B ions of No. 702 by alkali ions.

This observation leads to the conclusion that the replacement of Al, Si and B ions by alkali ions decreases Young's modulus of the resultant glass.

Figure 3 lists the same glasses as Figure 2 but with respect to the liquidus temperatures of the glasses instead of Young's moduli.

As would be expected, no general rules can be formulated regarding the effect of ion for ion replacement on the liquidus temperatures.

Figure 4 also contains most of the glasses shown on Figure 2. Viscosity measurements could not be made on a few of the glasses or the viscosities were much too low to be considered here.

From Figure 4 a few conclusions can be made. These are:

1. The substitution of Ba ions for Ca ions increases the viscosity of the melt.
2. The substitution of Mg ions for Ca ions increases the viscosity.
3. The substitution of Na ions for Li ions increases the viscosity.
4. The substitution of K ions for Na ions increases the viscosity.
5. The substitution of Si ions for Al ions increases the viscosity.
6. The substitution of B ions for Al ions decreases the viscosity.

It was observed that the area of glass formation was limited to compositions containing at least 50 cation percent of the acidic oxides, namely, alumina, silica, boron oxide, titania or zirconia. This area is shown in Figure 1, page 68. Glasses were formed in this series with as little as 20 cation percent and as much as 45 cation percent total alkaline earth oxides. The major portion of this alkaline earth oxide being in the form of calcium oxide. Substitution of magnesium oxide or barium oxide for calcium oxide produced glasses until about 20% of the total alkaline earth oxide was substituted. The alkali metal oxide content of these glasses was kept below 10 cation percent because of the tendency of these oxides to lower the modulus of the glass. Complete substitution of lithium oxide or potassium oxide for sodium oxide was found to be possible.

The color of these glasses was found to be dependent on the composition and to the melting history of the glass. Glass compositions near the limit of glass formation, that is, nearly 50 cation percent acidic components, gave blue or light green colored glasses, whereas glasses containing more than 50 cation percent acidic components gave light amber to colorless glasses. The light amber to colorless glasses which were originally melted in a gas fired furnace 2900°F. turned dark brown while in an electric muffle furnace for viscosity measurements. This color change from light amber to dark brown was found to be reversible. Remelting of the glass in the gas fired furnace restored the light color. The colors observed in these glasses was thought to be dissolved platinum from the platinum crucibles. However, the weight loss of the crucibles used for melting these glasses was found to be less than for platinum crucibles used for melting standard silicate glasses. No reasonable explanation for the color changes has been found.

The surface tension of these glasses was determined for only the two representative samples, No. 390 and No. 507. No. 507 was found to have a surface tension between 370 and 360 dyne-centimeters over the temperature range 2400°F. to 2800°F., while over this same temperature range, No. 390 had a surface tension from 398 to 388 dyne-centimeters. This can be compared to a surface tension of approximately 325 dyne-centimeters for standard textile glass. The surface tension was measured by the maximum bubble pressure method described in Appendix IV.

The dielectric properties of three of these glasses was determined at 9,455 megacycles by E. R. Schatz at Carnegie Institute of Technology.

No. 508 had a dielectric constant of 9.17 and a loss tangent of 0.006; No. 508-B, dielectric constant 8.94, loss tangent 0.005; No. 395, dielectric constant, 9.28, loss tangent 0.009. Our standard textile glass has a dielectric constant of 6.33 and a loss tangent of 0.006.

The addition of BeO as the oxide to the calcium aluminate compositions was not attempted because of the toxicity of this oxide. The addition of BeO from beryl,  $2 \text{ BeO} \cdot \text{Al}_2\text{O}_3 \cdot 6 \text{ SiO}_2$ , was made in Compositions Nos. 505B, 506 B, 507 B, 508 B and 509 B. BeO was substituted for CaO in these compositions to the extent that all of the SiO<sub>2</sub> in the composition was from the beryl. These compositions had higher elastic moduli than the corresponding glasses Nos. 505, 507 and 509 but they had higher liquidus temperatures and tended to devitrify on cooling.

An exploratory search for high modulus glasses was made in the stannic oxide system. Approximately 190 compositions were investigated which contained from twenty-five to seventy cation percent stannic oxide. The remaining cation of these compositions contained varying amounts of the alkali oxides, the alkaline earth oxides, aluminum oxide and silica. Small quantities of glass were made in this system, but not in sufficient quantity for physical property measurements. Devitrification of the melts and high melting temperatures were the major obstacles. Clay crucibles were used for all the exploratory melts in this field because of attack on platinum by the tin. In several cases, the glass which was formed in the melt was due to increased silica and alumina in the composition from the melting crucible.

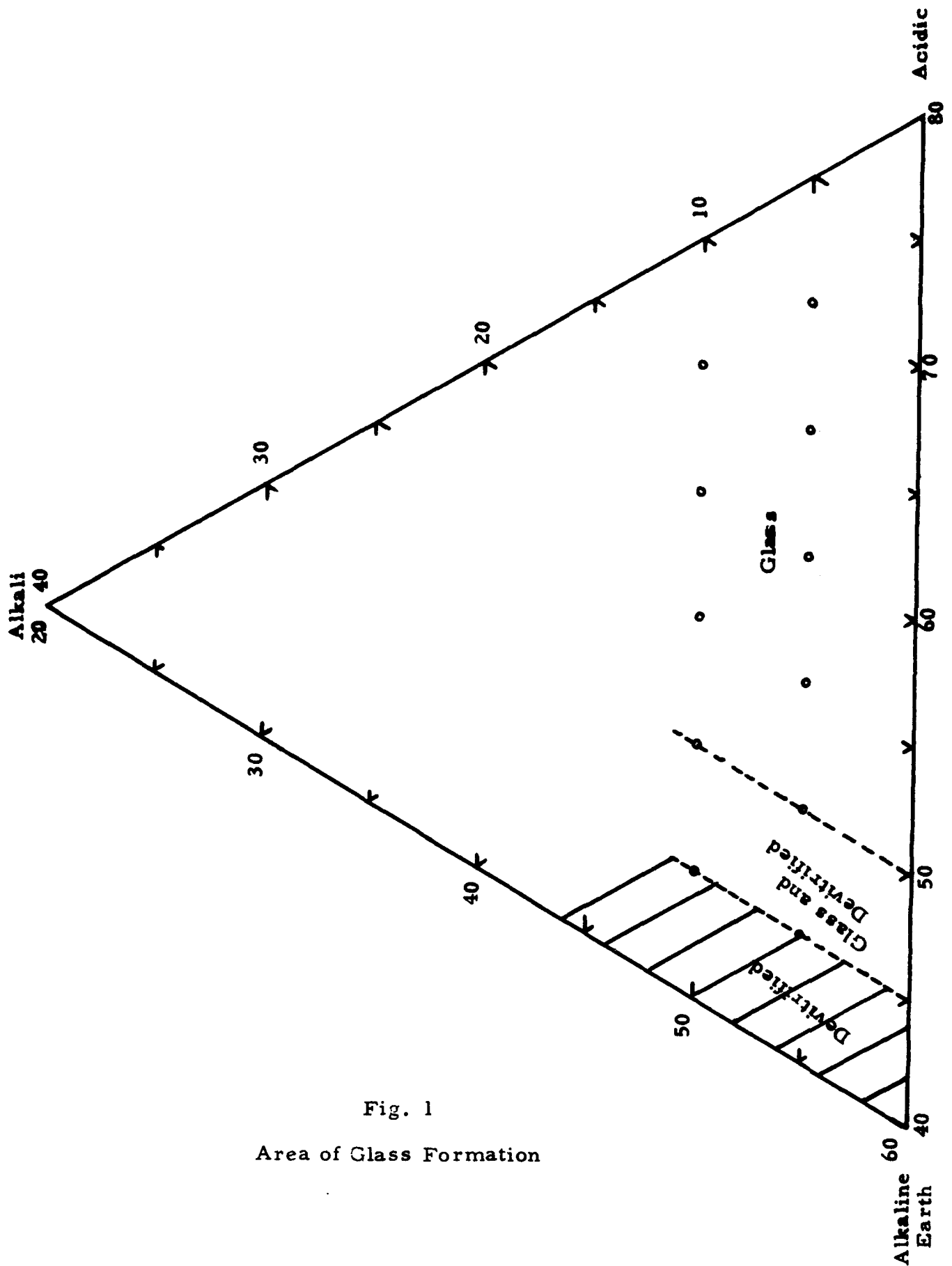


Fig. 1  
Area of Glass Formation

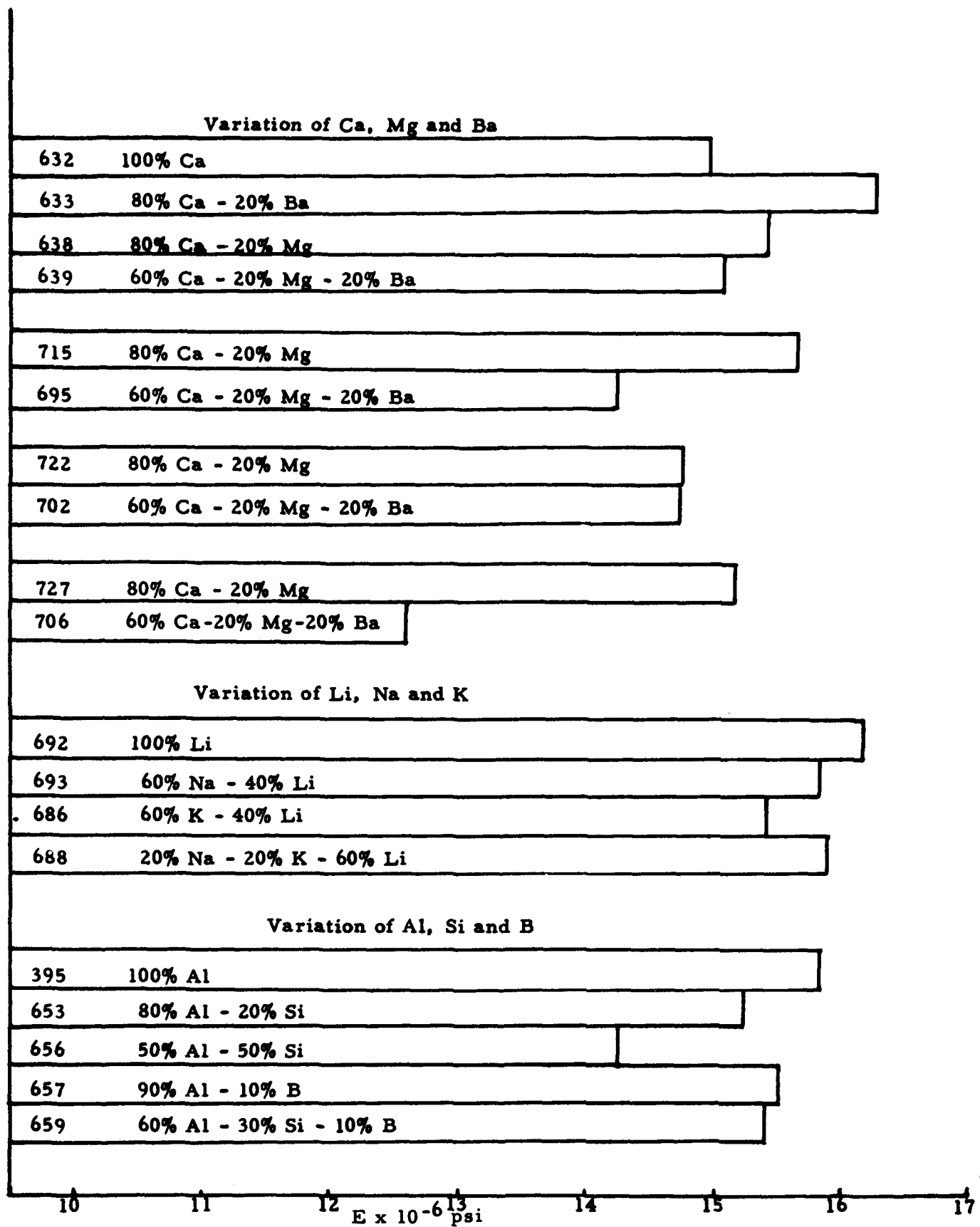
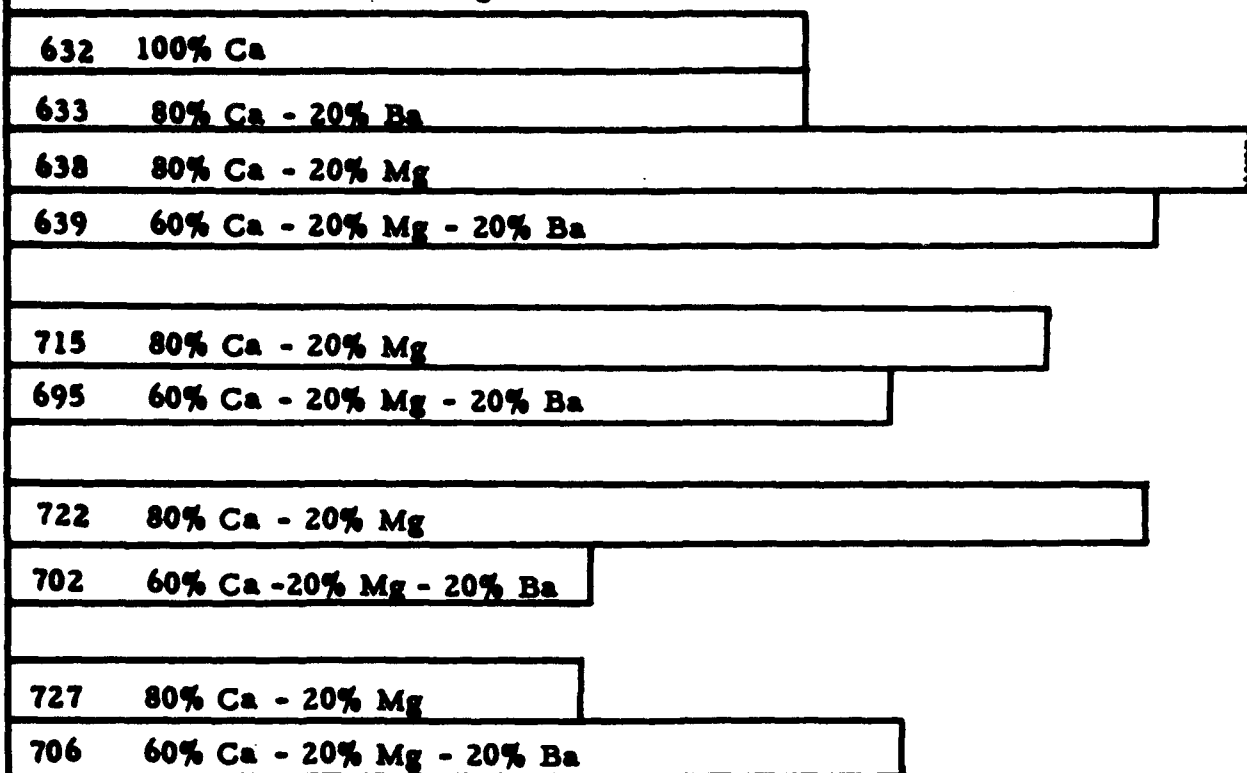


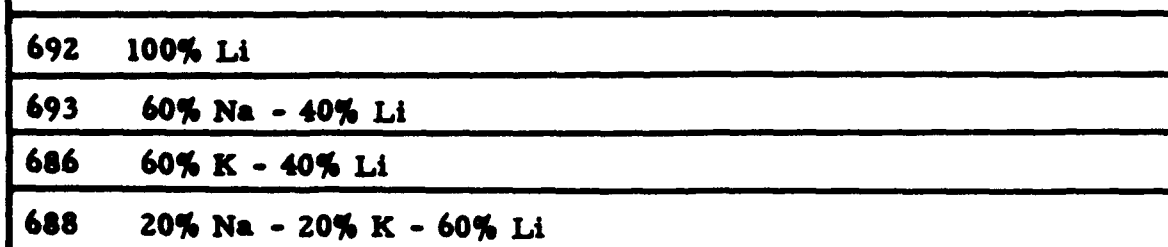
Fig. 2

Young's Moduli of Annealed Glasses

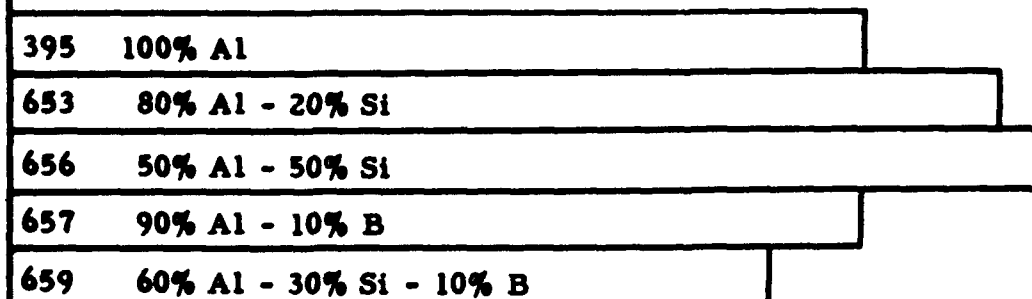
### Variation of Ca, Mg and Ba



### Variation of Li, Na and K

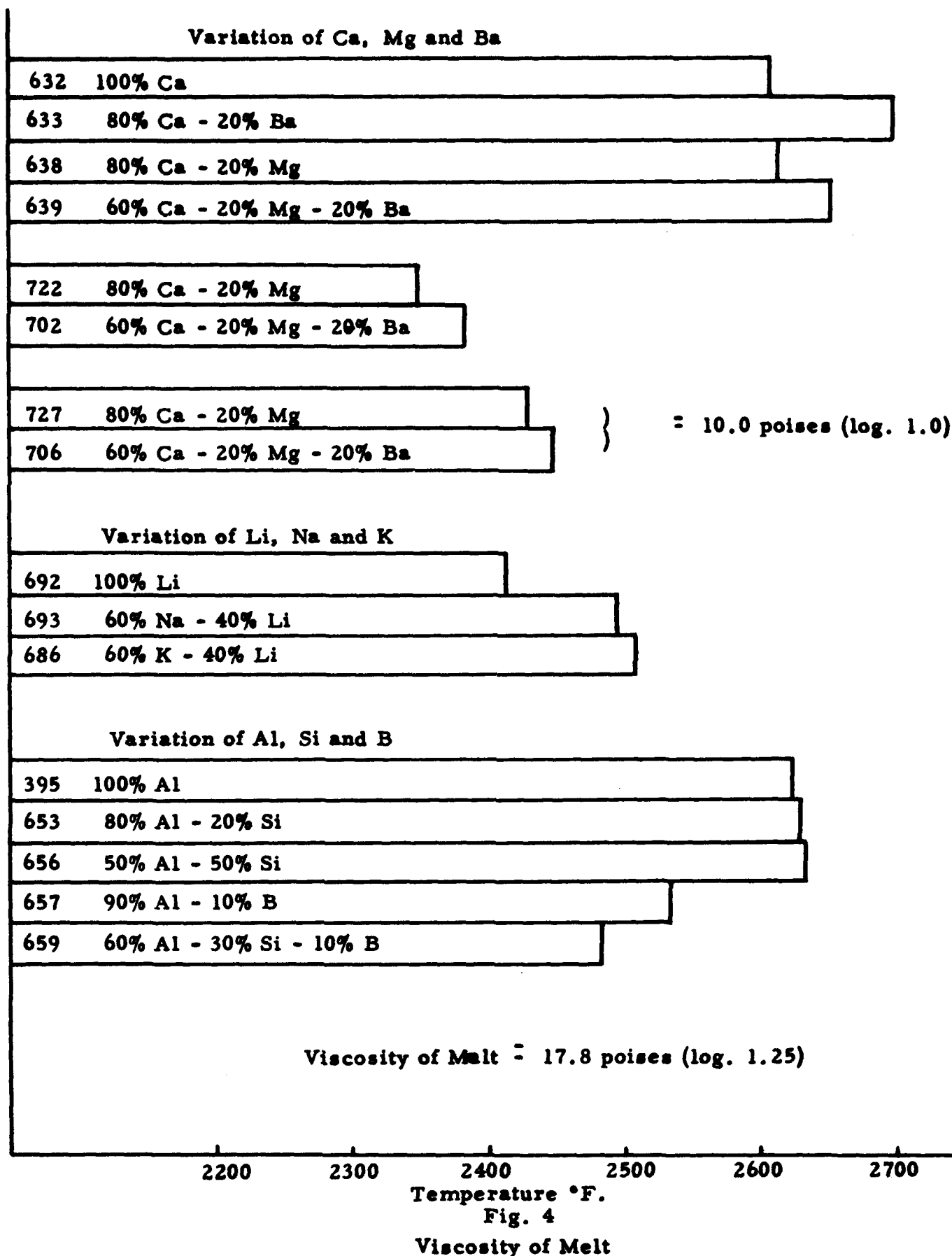


### Variation of Al, Si and B



2200 2300 2400 2500 2600 2700  
Temperature °F.

Fig. 3  
Liquidus Temperatures



#### IV. FIBER FORMATION STUDIES

The basic tool used in this investigation for the study of formation of continuous type fiber was the one hole bushing described in Appendix VI.

Nearly all the glasses in this study were found to be impossible to form into continuous type fibers in the one hole bushing for one of two reasons:

1. The melting temperature was too high to be practical to use in platinum, or
2. The viscosity of the glass was too low above the liquidus temperature and the glass would not form fibers continuously without devitrification of the glass in the bushing.

The glasses studied in a one hole bushing are shown in Table II and Table IV. All glasses shown on Table II could be formed in clear patties relatively free of devitrification. However, when they were placed in a one hole bushing, nearly all would devitrify when the temperature was sufficiently lowered to produce fibers. Various techniques were tried to overcome this devitrification problem. The most satisfactory of these was an air jet directed at the base of the cone or the end of the tip. Using this technique, small quantities of fiber were produced of Compositions Nos. 492, 506, 508 and 511. Even this technique, however, failed to yield a continuous operation since devitrification of the glass in the forming cone occurred after a few minutes operation.

Of all the glasses tried in the one hole bushing, Glass No. 508 shown in Table II was the most easily formed and was the only glass which could be fiberized continuously with no trouble with devitrification. Composition No. 508 was, therefore, used for all subsequent fiber formation studies. Fibers were always prepared to have a diameter of approximately 0.00040 inch.

Composition No. 508 shown in Table II had a bulk annealed modulus of  $15.42 \times 10^6$  psi. The same glass when formed into fibers had a modulus of  $13.25 \times 10^6$  psi.

Webster Capps of the National Bureau of Standards measured the elastic properties of No. 508 in bulk form by their methods. He reported elastic moduli of  $15.8 \times 10^6$  psi,  $15.5 \times 10^6$  psi and  $15.5 \times 10^6$  psi as the result of three measurements. The shear modulus of this glass was also determined and found to be  $6.25 \times 10^6$  psi. Density of this glass is 2.91 grams per milliliter. The density of the fiber after formation could not be determined by our present method, because of the poor water durability of the glass. The density of the fiber, however, can be assumed to be somewhat less than 2.91 grams per milliliter of the annealed glass. These fibers could be heat-treated at 1100°F. to a modulus of approximately  $15 \times 10^6$  psi. Tensile strength

values for these fibers corresponded very well with the tensile strength of standard textile fiber. Virgin fiber has a strength of approximately 400,000 lbs./sq.in. Chemical durability of these fibers, as mentioned previously, is extremely poor compared to our standard textile glass. However, since the primary use of this glass is to be imbedded in a plastic, it is impossible at this time to determine how much chemical resistance the glass must have. This can be decided only after the glass-plastic laminates have been made and a reasonable life has been determined for them. These glasses, in both bulk and fiber form, are completely soluble in hydrochloric and insoluble in hydrofluoric acid.

The next step in the study of the fiber formation of these glasses was a trial in a multiple tip unit. This unit contained eight tips having various bore sizes and tip lengths. Several modifications of this unit resulted in a unit which could be operated continuously with Composition No. 508. This unit was operated for several weeks continuously and was finally shut down due to contamination of the tips. Contamination of the tips was not due to the glass itself, but rather to the stainless steel probe used in starting the fibers.

Using the information gathered from the study of the one hole bushing and the six and eight tip units, a seventy-eight tip unit was constructed for the production of the strand. Difficulties were immediately encountered with this unit because of temperature distribution across the tip area and difficulties of trying to start fiber formation. The best temperature distribution that could be obtained on this bushing never allowed fiber formation from all the tips simultaneously. This unit was eventually shut down because of freezing of all of the tips due to devitrification. A second unit was constructed which had a better heat distribution than the first and operated at a higher temperature than the first. A maximum of approximately twenty tips could be operated simultaneously on this bushing. Temperature control of this bushing was the major difficulty. If the bushing was operating at too high a temperature, devitrification stopped the tips. This bushing was finally closed down after all the tips were closed by devitrification to the point where they could no longer be cleared. No samples of strand were ever produced on this type of bushing. Further developments of tips for this large size bushing will be required before strand will be produced.

## V. GLASS-PLASTIC COMBINATION STUDIES

Glass fibers produced on the six tip unit were used to construct glass-plastic combinations in the form of fishing rod tips. (Appendix VIII). Glass fibers are in these test samples as individual filaments because the small unit on which they were produced did not permit the formation of strand. Glass samples were collected by cutting off the pulling collet below the bushing a hank of fiber containing approximately 40,000 individual filaments. If a coupling agent was applied, it was applied during the forming operation. The hank, after being cut from the winding collet, was saturated with resin, hung vertically under tension, and wrapped with cellophane tape to form the rod. The formed rod was then heat-treated to set the resin.

Table V shows the results of the measurements of flexural strength, Young's modulus and ignition loss of these rods. Standard textile glass rods were produced for comparative purposes, since no comparison could be made between these rods and similar rods produced from a strand produced on a standard commercial textile unit. Flexural strengths and Young's modulus for standard textile glass rods reported in Table V are lower than those normally found for this type rod sample produced from strand. This is probably due to the method of production of the samples. The highest strength and the highest modulus rods produced in this investigation were prepared from No. 508 with Volan A coupling agent.

Heat treatment of fibers of No. 508 with Volan A coupling agent applied destroyed the fibers. Heat treatment could be given to fibers with vinyl-trichlorosilane coupling agent, but no improvement in the strength or the modulus was observed in the glass-plastic rod, as compared to fibers not heat-treated. An attempt was made to use silicic acid as a lubricant during the forming operation, heat treating the resulting fiber and applying Volan A coupling agent. These fibers resulted in the lowest strength glass-plastic rods produced.

Because of the failure of the larger type forming unit containing 78 holes, no glass-plastic rod samples were produced from strand. Better comparison between the calcium aluminate glasses and standard textile glass will be possible whenever rods of this type can be produced from strand instead of individual filaments. Individual filaments are difficult to fabricate into test rods because of unequal loading of all filaments during the formation of the glass-plastic rod.

TABLE V

## PHYSICAL PROPERTIES OF GLASS-PLASTIC COMBINATIONS

| <u>Glass</u> | <u>Coupling Agent</u>  | <u>Resin</u>   | <u>No. of Samples</u> | <u>Average Flexural Strength, psi</u> | <u>Average No. psi x 10<sup>-6</sup></u> | <u>Ignition Loss in % loss</u> |
|--------------|------------------------|----------------|-----------------------|---------------------------------------|------------------------------------------|--------------------------------|
| Std. Textile | Volan A                | Plaskon 911-11 | 9                     | 111.9                                 | 5.21                                     | 29.05                          |
| Std. Textile | None                   | Plaskon 911-11 | 22                    | 113.0                                 | 5.10                                     | 34.0                           |
| Ca 508       | None                   | Plaskon 911-11 | 12                    | 103.2                                 | 6.85                                     | 26.98                          |
| CA 508       | XF444                  | Plaskon 911-11 | 12                    | 130.0                                 | 6.39                                     | 29.76                          |
| CA 508       | XF444                  | Plaskon 911-11 | 18                    | 150.3                                 | 6.90                                     | 25.43                          |
| CA 508       | Volan A                | Plaskon 911-11 | 18                    | 178.5                                 | 7.23                                     | 38.25                          |
| CA 508       | Vinyltrichloro-silane  | Plaskon 911-11 | 18                    | 154.1                                 | 6.67                                     | 28.09                          |
| CA 508       | Vinyltrichloro-silane  | Plaskon 911-11 | 6 (heat treated)      | 135.4                                 | 5.45                                     | 39.39                          |
| CA 508       | Silicic Acid & Volan A | Plaskon 911-11 | 10 (heat treated)     | 68.4                                  | 6.34                                     | 16.61                          |
| CA 508       | Silicic Acid           | Plaskon 911-11 | 9                     | 104.7                                 | 3.72                                     | 50.55                          |

## VI. GENERAL CONCLUSIONS AND SUMMARY

The accomplishments and conclusions that can be drawn from this investigation are as follows:

1. Glasses in the calcium aluminate series can be produced which have bulk elastic moduli between  $14 \times 10^6$  and  $17 \times 10^6$  psi.
2. Fibrous glass has been produced from a glass having a bulk annealed modulus of  $15.42 \times 10^6$  psi, resulting in a fiber having a modulus of  $13.25 \times 10^6$  psi.
3. Heat treatment of resulting fiber will restore the modulus to nearly  $15 \times 10^6$  psi.
4. Fibers have been produced from a one hole bushing and from small multiple hole bushings, but no fibers were successfully produced from large production-sized units. Further development work in bushings will be required before commercial production of these glasses will be feasible.
5. Glass-plastic combinations have been produced which had properties equivalent to or greater than glass-plastic combinations produced from our standard textile glass in a similar manner.

## VII. RECOMMENDATIONS

A further worthwhile compositional investigation could be the addition of beryllium oxide in larger quantities than was practical in our laboratories. The few glasses produced in our laboratory containing beryllium oxide were produced from beryl, beryllium aluminate silicate. Beryllium oxide itself was not used as a raw material because of its toxicity. It is believed that additions of beryllium oxide in substitution for calcium oxide would lead to large increases in Young's modulus of the glasses. This is in agreement with the trend observed in the increases in modulus as we go from barium oxide to calcium oxide to magnesium oxide in the alkaline earth series.

Search for high modulus glass in tin oxide, zirconium oxide, and titanium dioxide fields were unsuccessful, but if higher meltline temperatures could be used, this possibility of high modulus glasses could again be explored.

## VIII. BIBLIOGRAPHY

1. Morey, George W. The Properties of Glass, Second Edition, American Ceramic Society Monograph No. 124, Reinhold Publishing Corporation, 1954. pps. 302-307.
2. Zachariasen, W. H. Journal American Chemical Society. 54, 3841, (1932).
3. Glaze, F. W. Paper given at the Fall Meeting of the Glass Division of the American Ceramic Society at Rochester, New York. 1953.
4. Sun, K. H. U.S. Patent No. 2,466,508. 5 April 1949.
5. Sterner, J. H. and Eisenbud, M. Epidermology of Beryllium Intoxication, Industrial Hygiene and Occupational Medicine. 4, 123 (1951).
6. Crossman, G. C. and VandeMark, W. C. Microscopic Observations Correlating Toxicity of Beryllium Oxide with Crystal Structure, Industrial Hygiene and Occupational Medicine, 9, 481 (1954).
7. Washburn, E. W., Shelton, G.R., and Libman, E.E., Univ. Ill. Eng. Expt. Sta. Bull., 140, (1924).
8. English, S.J., J. Soc. Glass Tech., 12 107 (1928)
9. Lillie, H.R., J. Am. Cer. Soc., 12, 505 (1929)
10. Lillie, H.R., Phys. Rev. 36, 347 (1930)
11. Tammann, G., Z. Anorg. Chem., 87, 248 (1919).
12. Parmalee, C.W. and Monack, A.J., J. Soc. Glass Tech., 13, 322 (1929).
13. Dietzel, A., Sprechsaal, 62, 506, 524, 543, 562, 584, 603, 619, 638, 657 (1929).
14. Silverman, W.B., J. Am. Cer.Soc., 22, 378 (1939).
15. Graver, O.H., and Hamilton, E.H., J. Research Natl. Bur. Standards 44, 495 (1950) RP2096.
16. Jaeger, F.M., Z. Anorg. allgem. chem., 101, 1 (1917).
17. Parmalee, C.W., and Lyon, K.C., Univ. of Ill. Eng. Expr. Sta. Bull. 36, (81), 1939.
18. Nolle, A.W., J. App. Phys. Vol. 19, 753, Aug. 1948.
19. Tiede, R.L., "A Flow Type Viscometer for Measuring Glass Viscosity," presented at the American Ceramic Society Convention, April 1954 (to be published).

## APPENDIX I.

### Hot Stage Microscope

A method for investigating a large number of compositions as rapidly as possible was found in the use of the hot stage microscope.

The hot stage was made of a platinum strip, 1/2 inch wide, 2-1/2 inches long and 0.060 inch thick. A spherical depression 1/2 inch in diameter and 1/8 inch deep was made in the center of the stage to hold the sample. A platinum - 13% rhodium thermocouple was attached to the bottom of the sample depression for the temperature measurement.

The electrical power was supplied from a 110 volt - 60 cycle source and two variable transformers were used for the control of the temperature.

Observation of melting and devitrification on the hot stage was made with a wide field stereomicroscope as shown in Fig. 2.

The hot stage was surrounded by refractory insulation when in operation to eliminate temperature variations of the hot stage by ambient conditions. A colored glass shield was used between the hot stage and the microscope objective to cut down the light intensity and to protect the microscope from excessive heat.

The observation of melting temperature on the hot stage was very successful. The melting rates and temperatures could be determined in a comparative manner very rapidly.

Measurement of the liquidus temperature of the compositions on the hot stage was only a crude estimation because the observed liquidus was dependent on the rate of crystallization of the melt and the rate at which the temperature of the stage was changed. The rate at which the temperature was changed was held as constant as possible with the method of control used.

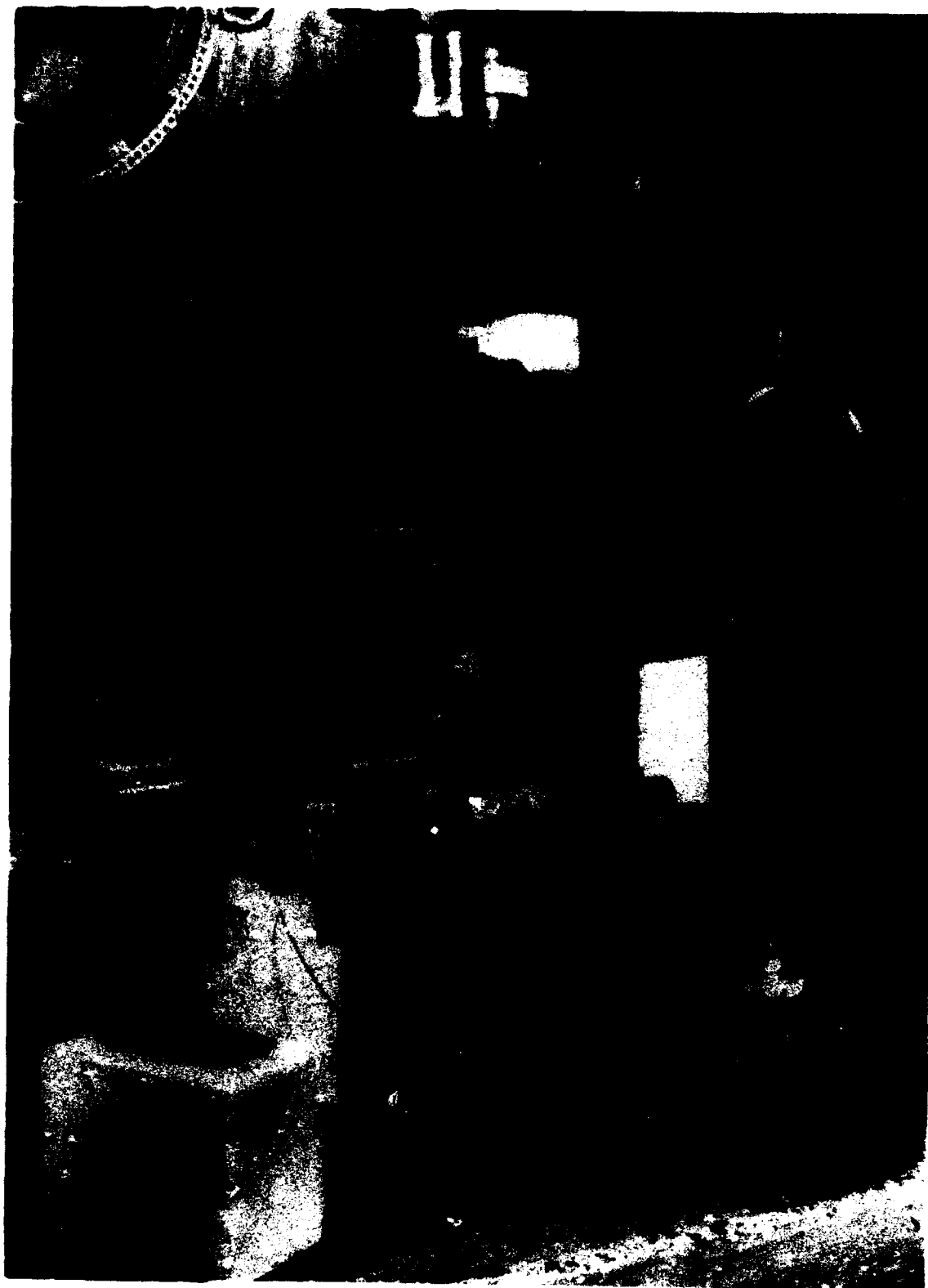


Fig. 5

Hot Stage Microscope

## APPENDIX II

### Determination of the Viscosity of Glass Melts with the Brookfield Viscometer

The Brookfield Synchroelectric Viscometer is a commercial instrument produced by the Brookfield Engineering Laboratories of Staughton, Mass. The principle of operation of these instruments is the accurate measurement of the torque on a spindle rotating at a constant speed in the viscous liquid.

This method of Margules has been widely used in the glass industry and its reliability well established. 7, 8, 9, 10 Lillie eliminated the need for a calibration factor by determining the correction to be applied to the finite length of the rotating spindle.

The combination of the Brookfield Viscometer with the spindles developed by Lillie have resulted in a method of measurement which is simple, fast and reliable. The calculated calibration of the Brookfield Viscometer was checked by measuring the viscosity of several of our standard glasses of known viscosity-temperature relationships.

Fig. 6 shows the viscometer mounted above the crucible furnace, the furnace and the furnace controls.

Fig. 7 shows the Brookfield Viscometer, the platinum spindle, the platinum linkage and the sample crucible.

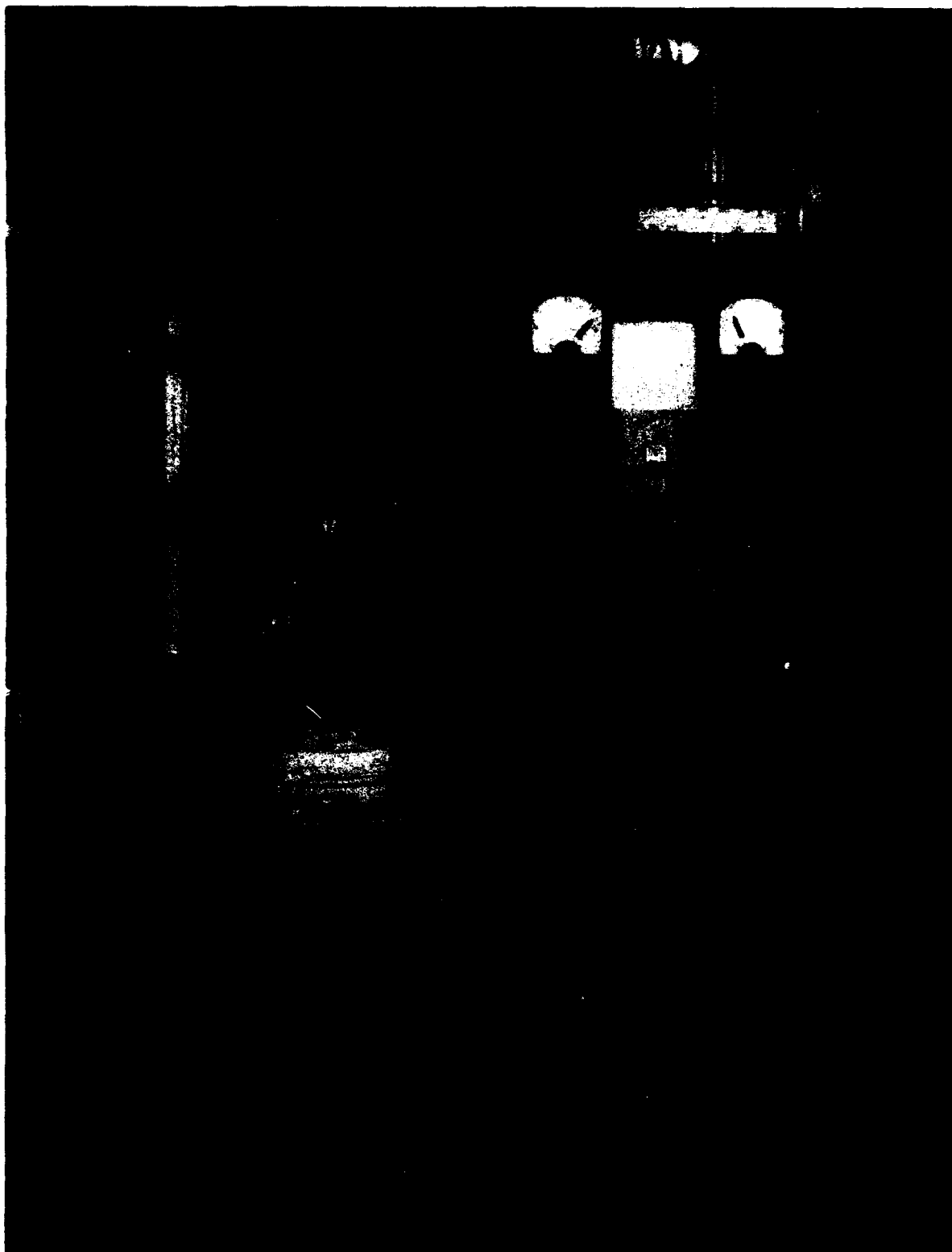


Fig. 6

Brookfield Viscometer Furnace and Control



Fig. 7

Brookfield Viscometer

## APPENDIX III

### Determination of the Liquidus Temperature by the Gradient Method

This method of determining liquidus temperatures was first described by Tammann<sup>2</sup>. The method has been used by several other investigators.<sup>12, 13, 14, 15</sup>

The gradient furnace and furnace controls are shown in Fig. 8. The furnace is a platinum resistance tube furnace, constructed to produce a temperature gradient from the center toward each end. The temperature gradient in this furnace is approximately 40-50°F. per inch.

The sample boat is shown in Fig. 9. The glass was crushed and placed in the boat. The boat was six inches long and a temperature difference of 300°F. existed between the opposite ends of the boat when in the gradient furnace.

For many commercial glasses, several days are required to reach equilibrium between the crystalline and glassy phases. The glasses studied in the current investigation devitrified very rapidly and only one to two hours were required for each determination.

Fig. 9 also shows the effect of a very rapid devitrification rate on the determination. The crystals which formed while the boat was cooling in air have hidden the liquidus in one of these samples. Sudden chilling of the boat as it was removed from the liquidus furnace prevented crystal growth in the glass during this period.

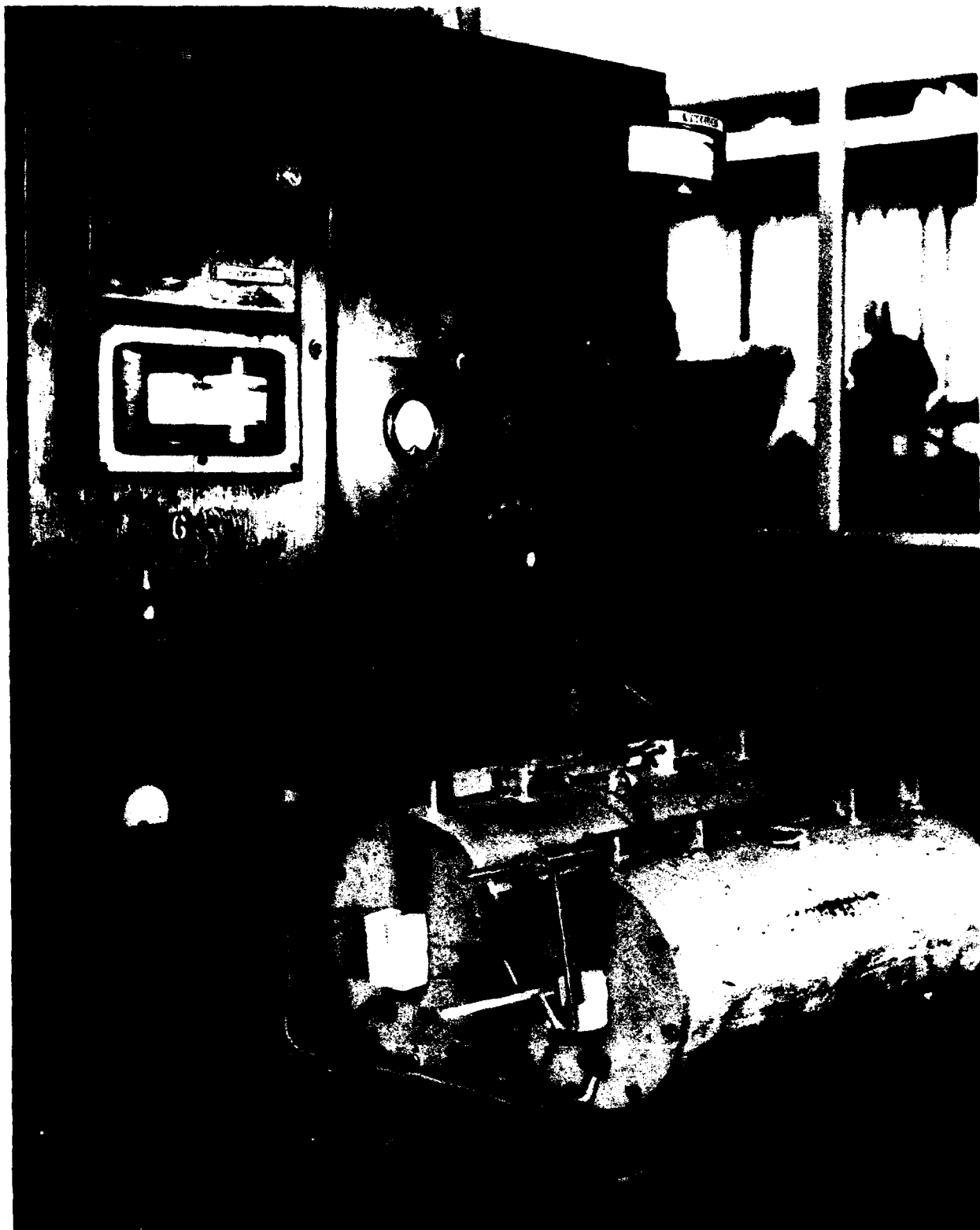


Fig. 8  
Gradient Liquidus Furnaces



Fig. 9

Liquidus Boats

## APPENDIX IV

### The Surface Tension of Glasses Determined by the Maximum Bubble Pressure Method

The maximum bubble pressure method was developed by Jaeger.<sup>16</sup> The method used in our laboratory is the modification developed by Parmalee and Lyon.

Fig. 10 shows the surface tension apparatus, furnace and furnace controls. Fig. 11 shows the platinum crucibles and the platinum capillary tips used in this apparatus. Air pressure was supplied from the laboratory compressed air supply and regulated to about 15 psi by a pressure regulator. The manometer reading was made with a measuring microscope used as a cathetometer. Measured surface tensions were reproducible to 1-2%, but the absolute error may be as great as  $\pm 10\%$ , particularly at low temperature and high viscosities.

The measurements required approximately one day for each glass. The capillary tip had to be kept clean and sharp, or serious error was introduced into the measurements. The individual bubbles had to be formed slowly to provide time for the glass to flow away from the bubble as it formed. High values were the result of too rapid formation of bubbles. Volatization from the surface was not observed as a serious problem.

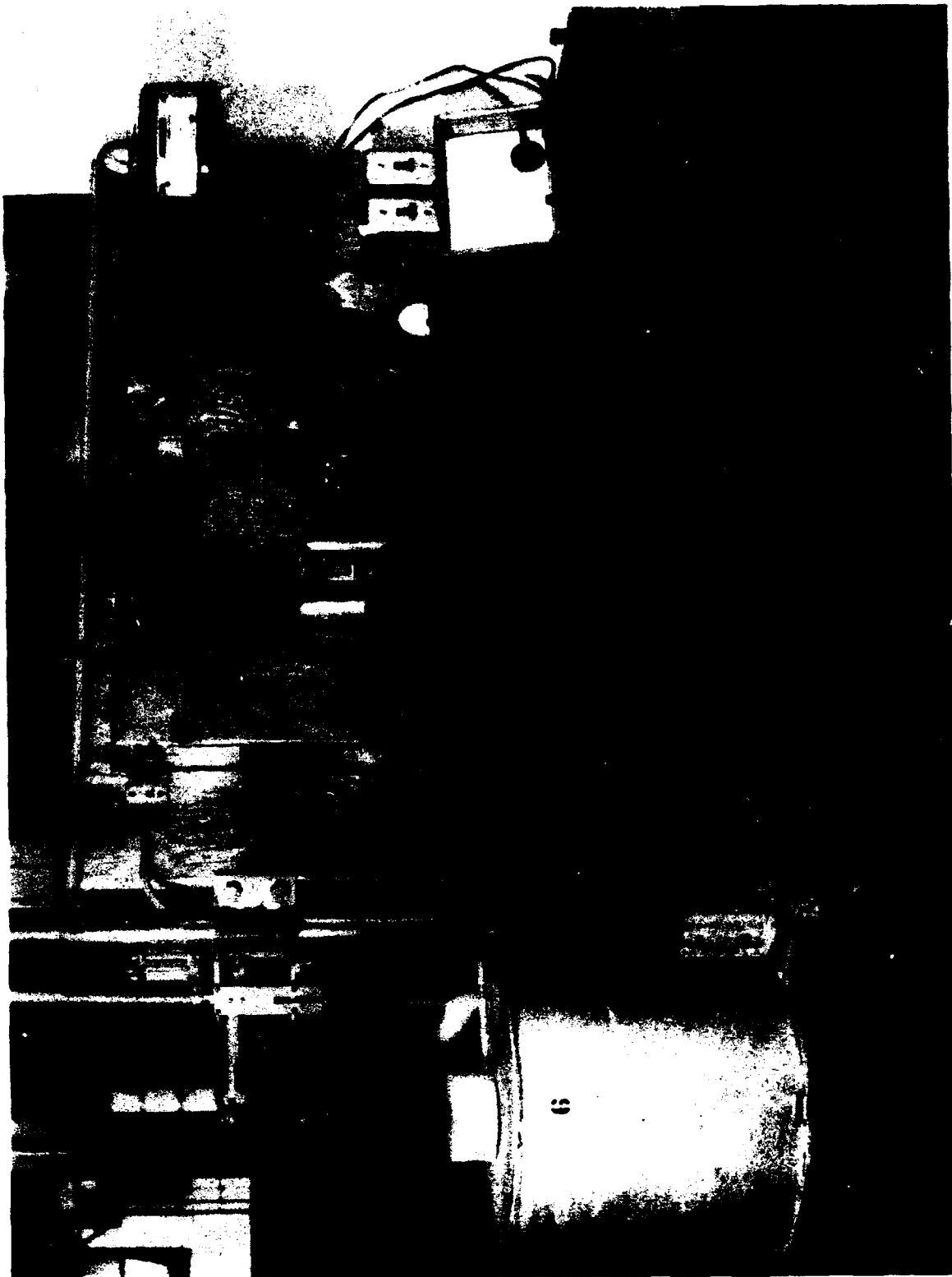


Fig. 10

Surface Tension Apparatus



Fig. 11

Crucible and Capillary Tube for Surface  
Tension Measurement

## APPENDIX V

### Measurements of Young's Modulus

Simple elasticity theory (that is, the theory by which we calculate the stresses and strains in structural members) assumes an elastic range of stresses in which the stresses and strains in a solid body are uniquely related and simply proportional to each other. The proportionality constants are called elastic constants, one of these being Young's modulus of elasticity.

$$E = \frac{\text{normal stress}}{\text{normal strain}}$$

The modulus is measured by applying a known stress and measuring the resulting strain. While the simple method is mechanical loading in a static system, a more convenient and more precise method in many cases is the dynamic or vibratory method. This latter method resolves itself into measuring the velocity of an elastic wave moving through the material since this is merely another method of elastically loading and unloading the material.

#### Measurement of Young's Modulus by Longitudinal Vibrations

For isotropic materials, the velocity of a longitudinal wave is determined solely by Young's modulus  $E$  and the density  $\rho$ .

$$E = \text{dynes/cm}^2$$

$$\rho = \text{gram./cc}$$

In practice, a bar of square cross-section was cemented on one end to a quartz crystal bar having the same resonant frequency. The crystal was then driven by a variable frequency oscillator and resonance of the composite was determined. The cemented joint had to be at a displacement antinode of the composite so that minimum stress was exerted on the joint.

The resonant frequency of the specimen was calculated from the following formula:

$$F_s = \frac{F_c(M_s + M_q) - F_q M_q}{M_s}$$

where  $F_q$  = resonant frequency of crystal (cycles/sec.)

$F_s$  = resonant frequency of specimen (cycles/sec.)

$F_c$  = resonant frequency of composite (cycles/sec.)

$M_s$  = mass of specimen (grams)

$M_q$  = mass of crystal (grams)

## APPENDIX V (Cont.)

then, knowing the length,  $l$ , of the specimen and the density,  $\rho$ , Young's modulus was calculated from the following relation

$$E = 4l^2 F_s^2 \rho$$

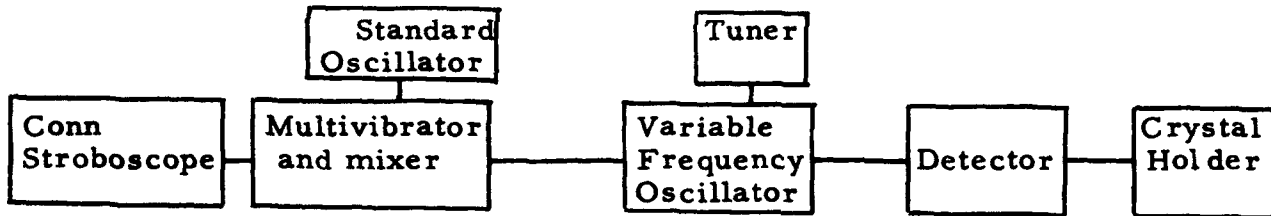
$E$  = dynes/cm<sup>2</sup>

$l$  = cm

$\rho$  = grams/cc

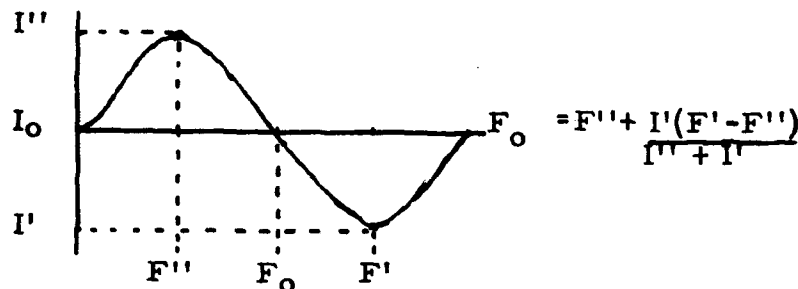
$F_s$  = cycles/sec.

A block diagram of the electrical circuit is shown below:



The standard oscillator was a controlled tuning fork, having a frequency of 1000 cycles per second with high harmonic content. This variable oscillator drove the crystal and was also mixed with the 1000 cycle signal and harmonics. This provided a beat signal which was fed to the Conn Stroboscope. For example, if the variable frequency oscillator was oscillating at 38,357.2 cycles per second, the beat notes produced with the 38th and 39th harmonics of the 1000 cycle oscillator were 357.2 cycles/sec. and 642.8 cycles/sec. This was fed into the Conn Stroboscope through a 0-500 cycle/sec. pass filter which attenuated the higher frequency. Then the lower frequency could be measured.

The detector was an electronic voltmeter which measured the voltage across a resistance in series with the crystal. This reading was then proportional to the current in the crystal. The current vs. frequency characteristic of a crystal is



The crystal was of square cross-section, with two opposite faces silver plated. The electrical connections and supports were at displacement nodes.

Fig. 12 shows the complete apparatus for the determination of Young's modulus of bulk annealed glass rods. Fig. 13 shows in detail the sample and sample mounting.

## APPENDIX V (Cont.)

### Vibrating Reed Measurement of Young's Modulus

The velocity  $V$  of a flexural wave traveling in a rod of radius, is given by the relation

$$V = \frac{\pi r}{2\lambda} \sqrt{E/\rho} \quad V = \text{cm/sec.}$$

where  $\lambda$  is the wave length in centimeters.

For the vibrating reed or fiber this relationship becomes

$$F_n = \frac{\pi K}{2L^2} \beta_n^2 \sqrt{E/\rho}$$

where  $K = \pi/4$  for circular cross-section of radius  $r$  (cm)

$F_n$  = resonant frequency at mode of oscillation (cycles/sec.)

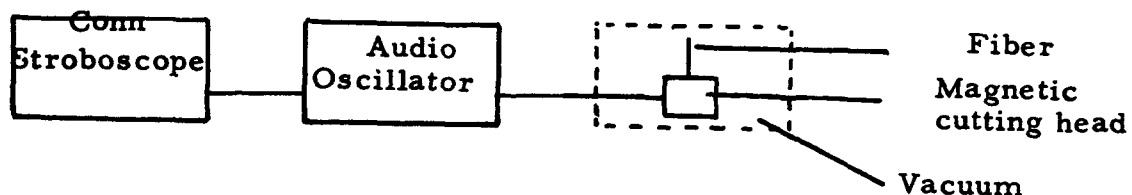
$L$  = length of fiber (cm)

$\beta_n$  - is a factor depending upon mode of oscillation

or  $E = \frac{16F_n^2 L^4}{\beta_n^4 \pi^2 r^2 \rho}$  for each mode of oscillation. (dynes/cm<sup>2</sup>)

Thus, Young's modulus can be calculated from measurements of resonant frequency for a particular mode of oscillation, fiber length, fiber diameter and density.

In practice, a magnetic phonograph cutting head was used to set the fiber to vibrating in one of its resonant modes of oscillation. This cutting head was driven by a variable frequency audio oscillator. As shown in the block diagram, the Conn Stroboscope was used to measure the resonant frequency.



# APPENDIX V (Cont.)

The modes of oscillation and  $\beta_n$  values are shown below:

|           |                                                                                   |                                                                                   |                                                                                     |
|-----------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|           |  |  |  |
| Mode      | 1                                                                                 | 2                                                                                 | 3                                                                                   |
| $\beta_n$ | .597                                                                              | 1.494                                                                             | $n - \frac{1}{2} \ (n > 2)$                                                         |

Fig. 14 shows the complete apparatus for the determination of Young's modulus on fiber samples. Fig. 15 shows the detailed mounting of the fiber sample.

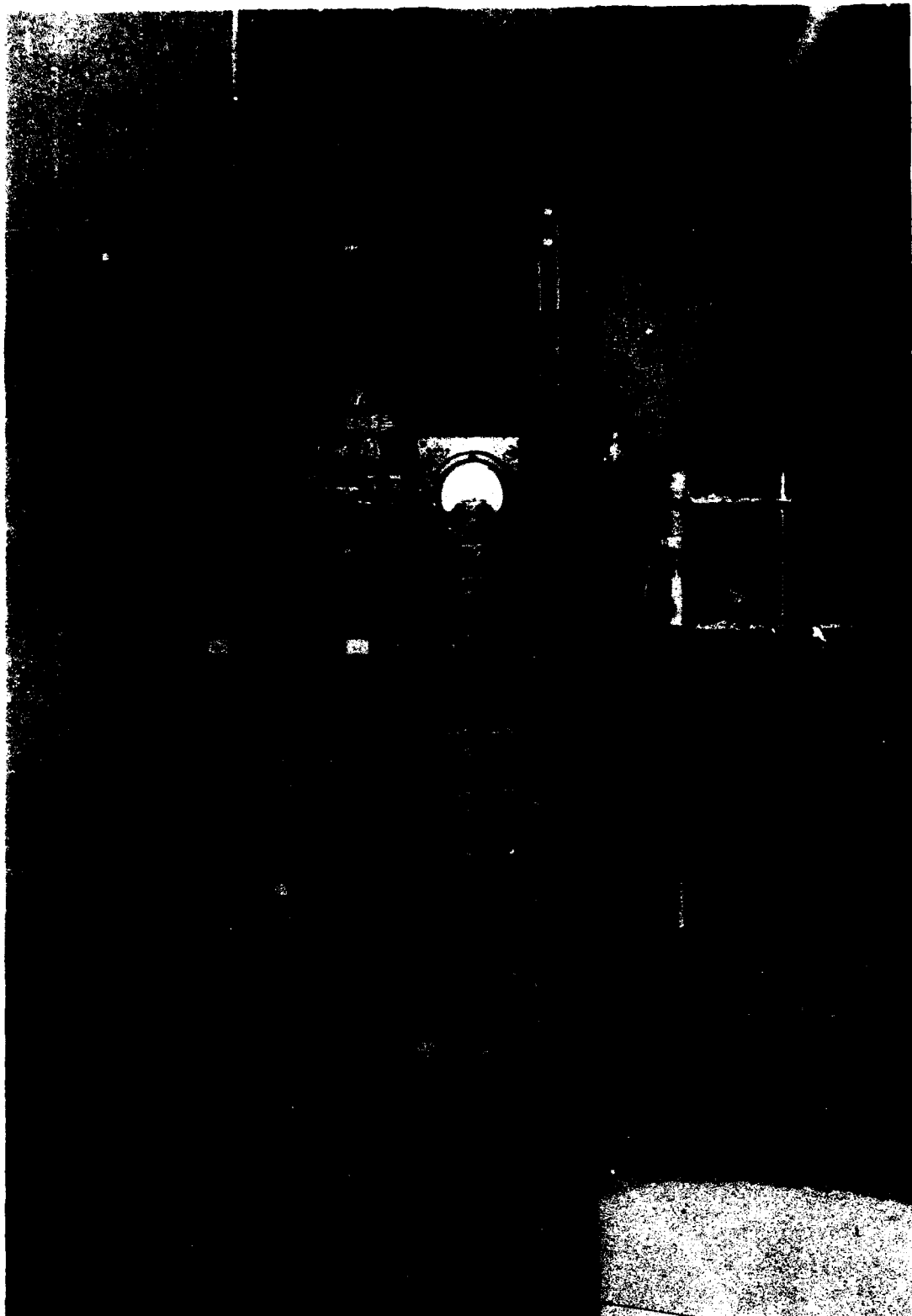


Fig. 12

Young's Modulus Apparatus for Bulk Samples

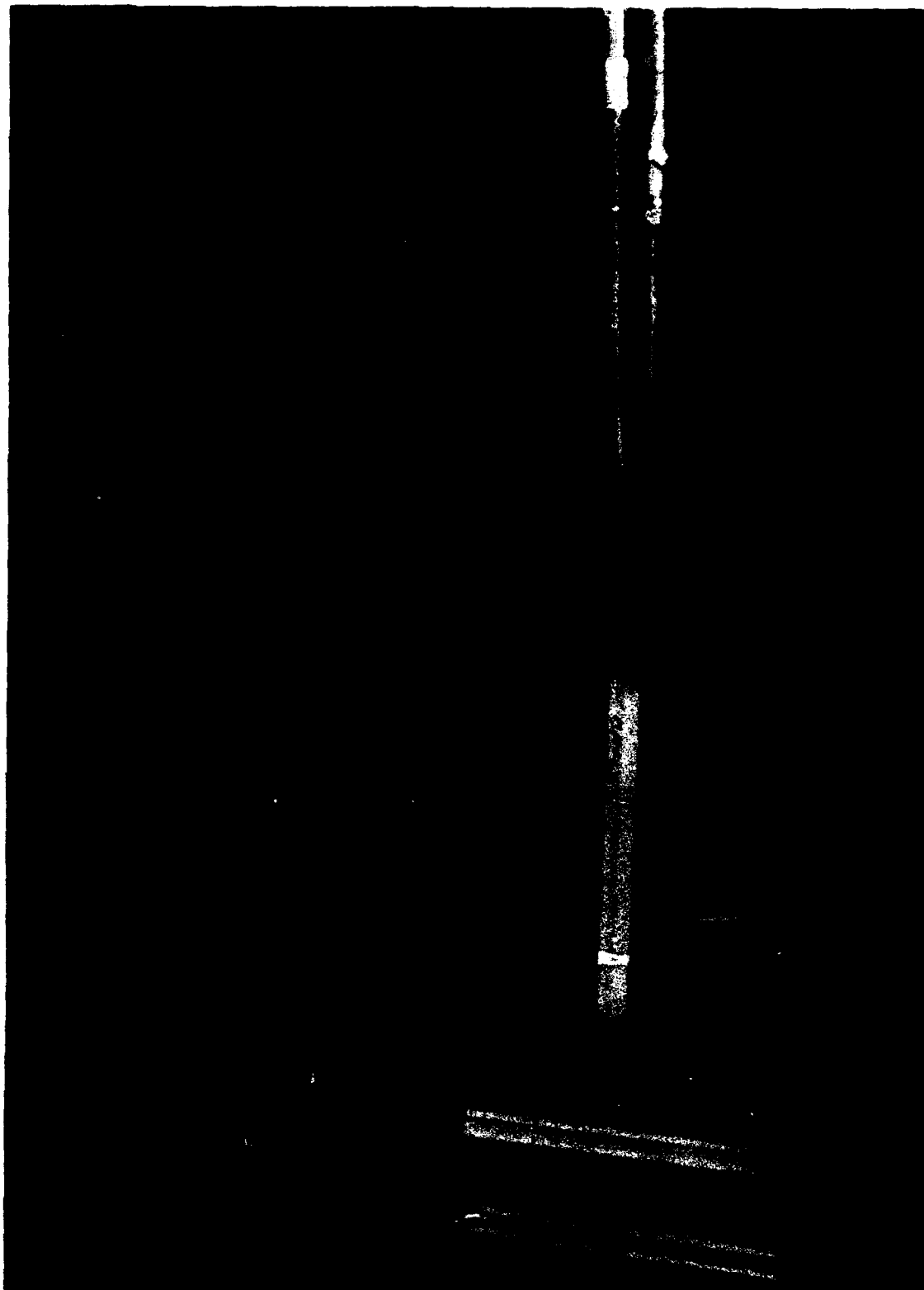


Fig. 13

Sample Mounting for Young's Modulus  
Measurement



Fig. 14

Young's Modulus Apparatus for  
Fiber Samples

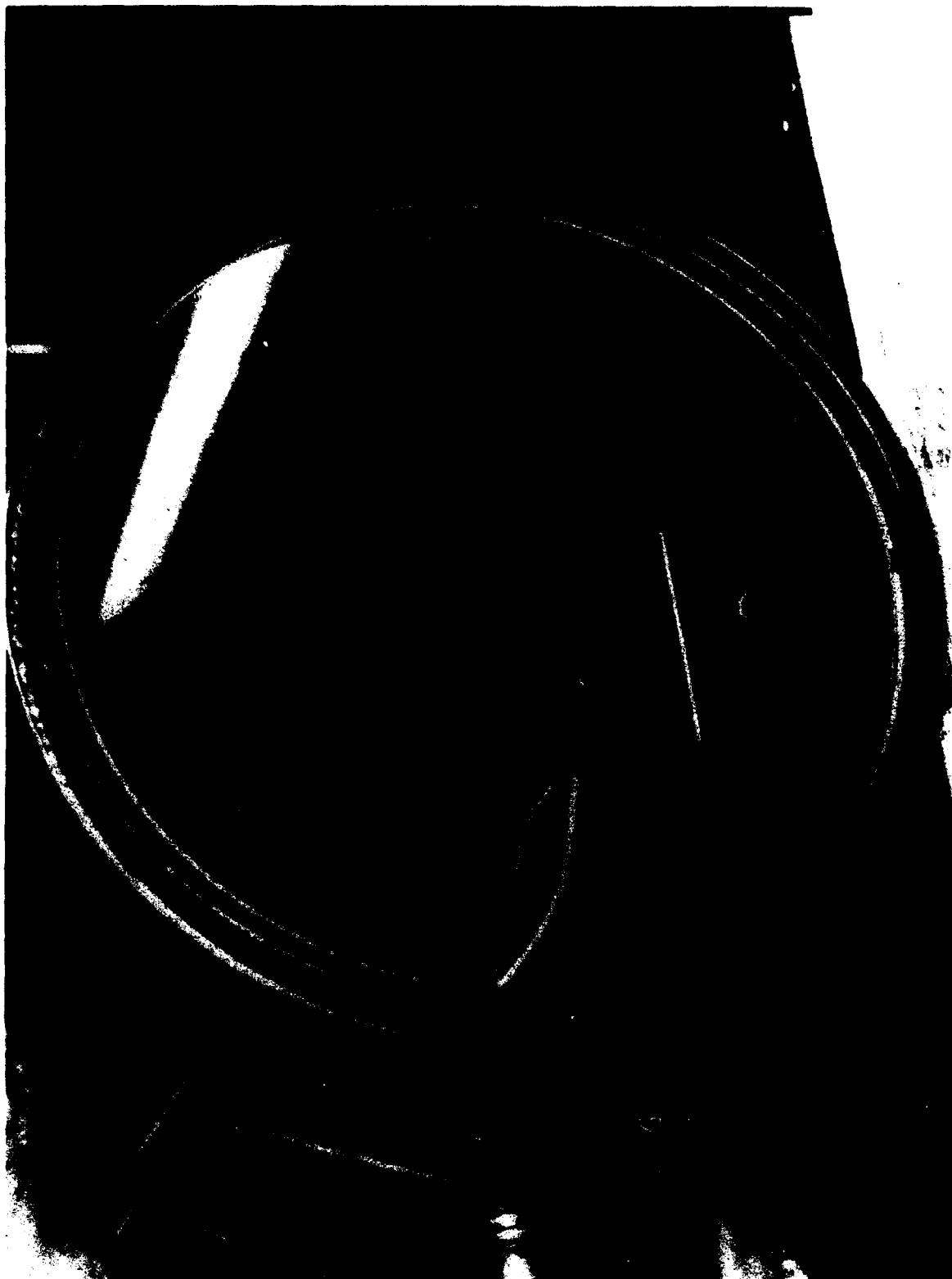


Fig. 15

Fiber Sample Mounting for Young's Modulus  
Measurement

## APPENDIX VI

### Fiber Forming Apparatus

The standard method of forming continuous glass filaments on a laboratory scale has been described by Tiede.<sup>19</sup> Many modifications of the simple one hole bushing can be used for investigating the feasibility of producing glass fibers.

Fig. 16 shows the complete assembly as it is used for a viscosity measurement as described by Tiede. Fig. 17 shows the platinum bushing without insulation.

The tip of the bushing can be varied in many ways. The metering hole which regulates the rate of flow of the glass into the tip can be varied to regulate the final fiber diameter. The tip can be counterbored or plain. Counterbored tips help prevent flooding of the bushing. The tip can be cooled by an air jet or water coolers to help stabilize the cone of glass from which the fiber is drawn.

The pulling speed or rate of fiber forming can be changed by using a variable speed motor on the pulling wheel. Rates of drawing from 1000 ft./min. to 9000 ft./min. can be obtained with our laboratory equipment.

Fiber diameter can be regulated by bushing temperature, metering orifice size or pulling speed. The most satisfactory combination of these variables must be found for each glass investigated.

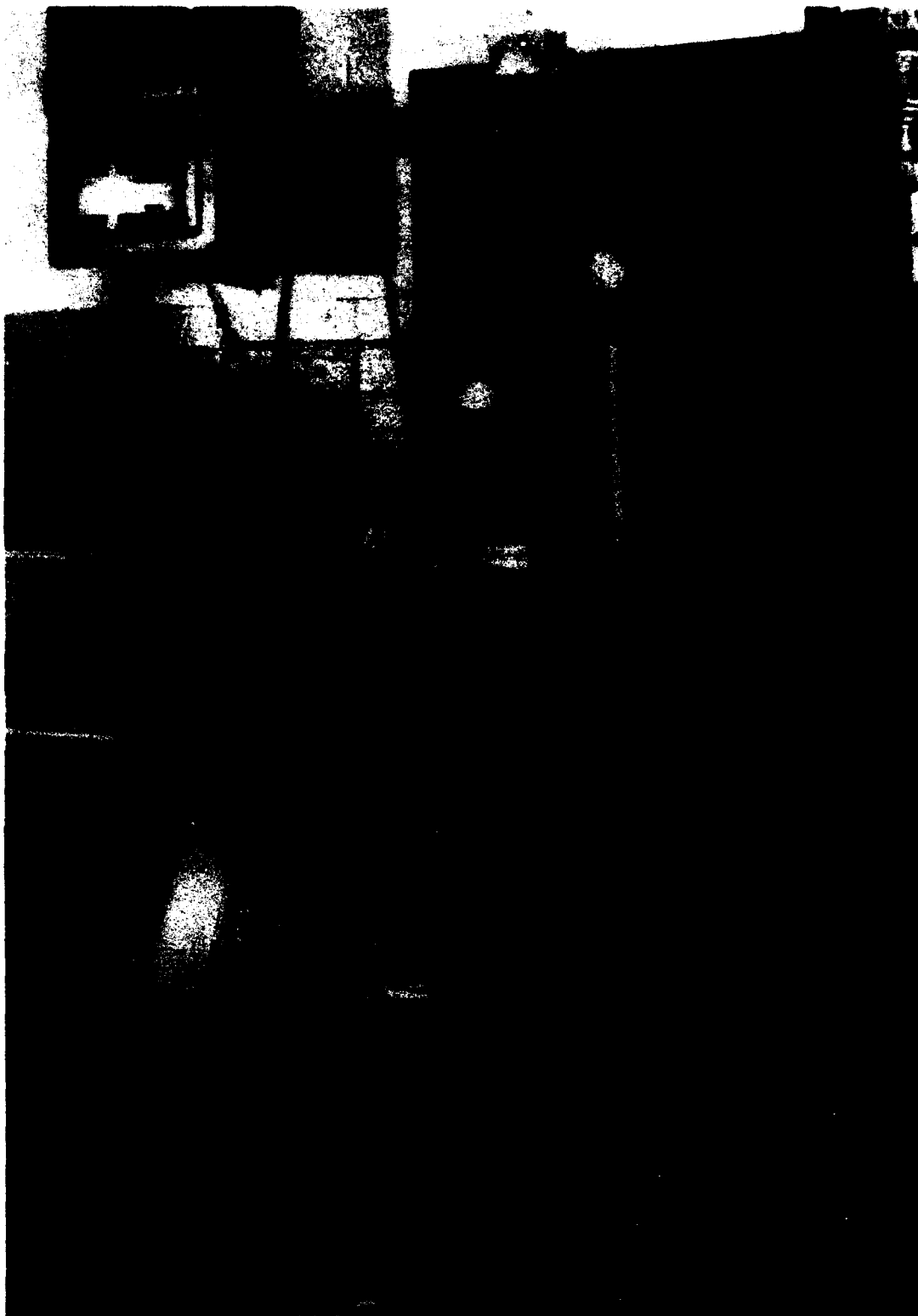


Fig. 16

One hole Bushing Apparatus



Fig. 17

One hole Bushing

## APPENDIX VII

### Single Fiber Tensile Tests

Single fibers are tested in simple tension on the constant rate of strain apparatus shown in Fig. 18.

This apparatus employed a cantilever beam type weighing cell with coupled LVDT (linear variable differential transformer). The LVDT was powered at 8000 cycles/sec. and the output signal from the LVDT after passing through the bridge-amplifier and rectifier, was fed to the X-axis of a Leeds and Northrup X-Y recorder. A signal, from a potentiometer coupled to the loading jaw, was fed to the Y-axis of the recorder, thus providing a load-elongation diagram for each fiber tested.

Fibers were taken from the fiber forming apparatus and mounted on wire holders for transfer to the testing machine, care being taken to eliminate damage to the fiber by handling. The fibers were secured to the jaws of the tensile tester with red sealing wax as shown in Fig. 19.

After each fiber was tested, a portion of the fiber was mounted on a microscope slide for measurement of fiber diameter. This measurement was made by projection microscopy at a magnification of 1000X. The tensile strength of each fiber was then calculated from the breaking load and the diameter (cross-sectional area).

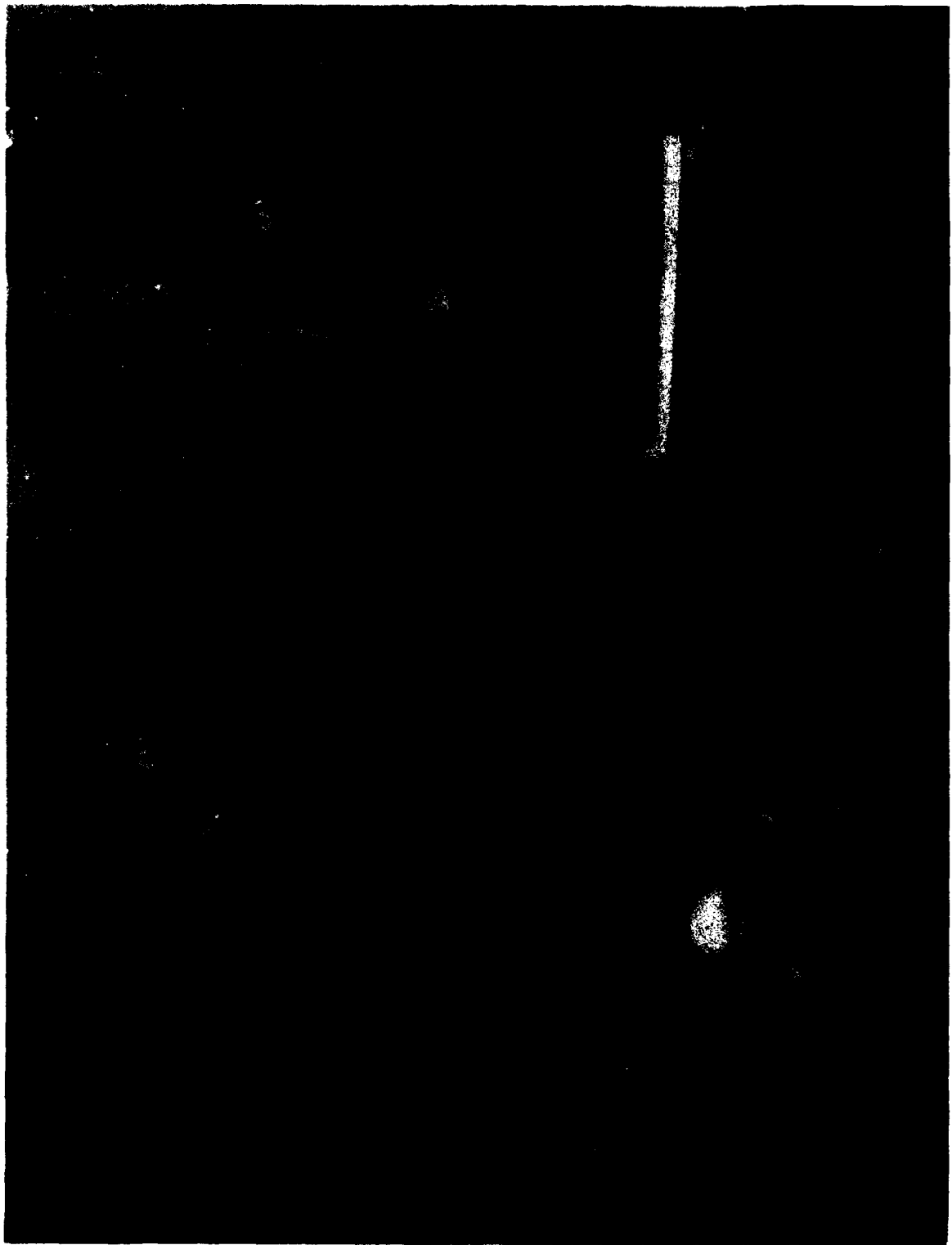


Fig. 18

Tensile Strength Measurement



Fig. 19

Sample Mounting for Tensile Strength  
Measurement

## APPENDIX VIII

### The Formation of Glass-Plastic Test Samples

The standard "fishing rod tip" test samples of fibrous glass-plastic materials are produced as follows:

1. A length of strand containing 204 filaments is impregnated with a thermosetting resin.
2. The impregnated strand is looped about two hooks approximately 20 inches apart until a strand of approximately 40,000 filaments is built.
3. The lower hook on the strand is stressed to hold the fibers straight and the entire rod of 40,000 filaments is wrapped, by machine, with cellophane tape.
4. The cellophane wrapped rod is heat treated to fix the resin and the rod is complete and ready for testing.

The equipment used in producing these samples is shown in Fig. 20.

The test rods produced in this investigation differed from the above procedure in that no strand of 204 filaments was available. The following procedure was therefore followed:

1. A hank containing approximately 40,000 filaments was cut from the winding collet of the one hole bushing.
2. The hank was impregnated with resin, suspended under tension and wrapped with cellophane tape in the same manner as the strand.
3. The wrapped rod was heat treated and tested.

This second procedure with hanks of fiber is not as satisfactory as with strand because it is extremely difficult to put equal tension on all the individual filaments while the rod is being formed. As a consequence, the strength and modulus values obtained for this second procedure are less than those found with strand.

These tests are indicative of the overall properties of the glass-plastic combination. Therefore, the glass properties and the coupling between the glass and plastic, both affect the test results.



Fig. 20

Preparation of Glass-Plastic Rod Samples