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TITLE

# CHARACTERIZATION OF COMMERCIAL ALUMINATE, SILICATE, AND ZERO-X MATERIALS.

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# CHARACTERIZATION OF COMMERCIAL ALUMINATE, SILICATE, AND ZERO-X MATERIALS

by

W. E. Gurwell
Fabrication Development
Fabrication Metallurgy

## Abstract

Lithium aluminate and lithium silicate powders (Lithium Corporation of America) and Zero-X pellets (Ferro Corporation) have been analyzed spectrochemically, by X-ray diffraction, and for lithium, carbon, and water content. These data are presented along with some important physical constants of the materials.

Aluminate and silicate powders are incompletely calcined, containing up to 3 wt% residual lithium carbonate. They have lithium contents that are sub-stoichiometric by as much as 20%. They have moisture contents up to 7 wt%. Aluminate powders contain a variable mixture of the $\alpha$ and $\gamma$ allotropes. Silicate powders have the single lithium meta silicate structure. Average particle size of the powders ranges from 75 to 100 microns.

Zero-X pellets are calcined completely, and have stoichiometric lithium content, about 105 ppm water, and a density of 1.83 gm/cc. Crystal structure is a solid solution of silica in $\beta$-Spodumene.

## Introduction

It is the purpose of this paper to characterize the behavior and chemical purity of lithium aluminate and lithium meta-silicate powders (made by Lithium Corporation of America, the major commercial supplier) and Zero-X pellets (synthetic petalite, made by Ferro Corporation, the sole commercial supplier).

In order to completely understand the behavior of these materials one must be familiar with the manufacturing processes. Available information on those processes is given within this report.

All three materials are produced by reacting lithium carbonate with alumina and/or silica powders according to the following reactions:

Lithium Aluminate

$$Li_2CO_3 + Al_2O_3 \xrightarrow{750-800^\circ C} 2LiAlO_2 + CO_2$$

42.0 wt% 58.0 wt% → 75.0 wt% 25.0 wt%



Lithium Silicate

$$Li_2CO_3 + SiO_2 \xrightarrow{>600^\circ C} Li_2SiO_3 + CO_2$$

55.2 wt% 44.8 wt% → 67.2 wt% 32.8 wt%

Synthetic Petalite (Zero-X)

$$2LiAlO_2 + 8SiO_2 \xrightarrow{\sim 1300^\circ C} Li_2O \cdot Al_2O_3 \cdot 8SiO_2$$

21.6 wt% 78.4 wt% → 100 wt%

(This aluminate is made by the same reaction as above.)

The aluminate and silicate powders are produced by calcining the powder mixture in a rotary kiln. Reaction is considered complete when the $CO_2$ evolution appears to stop (our analyses show that there is up to 3% unreacted carbonate in the aluminate and 1.5% in the silicate). The calcining may be followed by a short grinding step in order to break up large aggregates.

The lithium aluminate product is used as a flux in refractory enamels. The lithium silicate product is a powerful flux used in enamels, glazes, and coatings for welding electrodes.

Zero-X material is made by reacting blended silica and aluminate powders in a pelletized form. These pellets are then ground to a fine powder, slip cast into pellets, and sintered. The product is a low coefficient of expansion, thermal shock resistant body which was developed by Ferro Corporation for these properties.

## Discussion and Conclusions

The chemical purity of all three of the above products (see Table VII) is largely dependent on the alumina and/or silica purity. Lithium carbonate is a stable, stoichiometric compound which can be obtained in a chemically pure form easily and cheaply. The chemical purity of the final products is also dependent on completeness of reaction and stoichiometry of the carbonate plus alumina and/or silica mixtures. Both aluminate and silicate powders received to date from Lithium Corporation have had sub-stoichiometric lithium contents and residual carbonate (see Tables I and II). Aluminate powders also have residual alumina (see Table III, X-ray diffraction data for lithium aluminate). Zero-X pellets have stoichiometric lithium contents and low residual carbonate. (See Tables I, II, and V.)

Residual amounts of $Li_2CO_3$ are undesirable if the material is heated in a closed container above the preparation temperature. The elevated temperature would force reaction of the carbonate thus producing an appreciable partial pressure of $CO_2$. Also, lithium carbonate is said to react violently with molten aluminum[1] and may do so with other container materials at elevated temperatures.

$LiAlO_2$ has two crystallographic forms. The low form, $\alpha$, transforms irreversibly to the high form, $\gamma$, above 600° C with an accompanying 30% volumetric increase[2] (or 23% density decrease). The kinetics of the transformation increase with increasing temperature and the transformation occurs fairly rapidly at 900° C.[3] Aluminate powders received to date have had a variable $\alpha$ and $\gamma$ content running from about 50% $\alpha$ to near 75% $\alpha$ (see Table III, Batch 2 and Batch 3b aluminate, respectively). A sample containing 75% $\alpha$ heated to 1000° C for 6 hours had a residual $\alpha$ content of less than 10%. Obviously the percentage of alpha would influence the green and sintered densities of whiteware made from the aluminate powder. Also the

$\alpha$-$\gamma$ expansion (9% linear) is large enough to fracture any closed container if the powder is packed tightly into it.

$Li_2SiO_3$ (lithium metasilicate) has but one crystallographic form. (See Table IV.)

Zero-X (a synthetic petalite, $Li_2O \cdot Al_2O_3 \cdot 8SiO_2$) is a solid solution of silica in $\beta$-spodumene ($Li_2O \cdot Al_2O_3 \cdot 4SiO_2$) and is completely stable above 680°C (see Table X).

Differential Thermal Analysis of Aluminate Powder

A sample of aluminate powder from Batch 3c has been submitted to differential thermal analysis. Four thermal effects (reactions) were found on heating to 1500°C. Only one of the reactions was reversible, on cooling. On heating, there is a peak at about 200°C which corresponds to water evolution. The next peak is a broad endotherm at about 450°C which is most likely decomposition of lithium hydroxide. At 975°C there is another broad endotherm. According to Maslova and Lileev[6] this endotherm is probably the reaction of $Li_2O$ with aluminum oxide. The last peak is an exotherm at 1280°C on heating. This last reaction, the only reversible one, occurs at 1235°C on cooling, and is probably related to some type of crystallographic change. This peak was also found by Hummel.[7] He prepared $LiAlO_2$ powders by reaction of the carbonate and alumina at 1500°C for 15 hours. Using more carefully prepared powders, Strickler et al[9] could not confirm Hummel's earlier data. Hummel's later work[8] showed that a considerable amount of lithium spinel, $LiAl_5O_8$, is formed at these temperatures due to lithia loss. $LiAl_5O_8$ has a reversible order-disorder reaction that occurs between 1250 and 1300°C on heating. Since the Batch 3c aluminate powder has a low lithia content it is most probable that there is a significant amount of the lithium spinel present. It follows then that this last thermal effect is the order-disorder reaction of the spinel phase within the

Batch 3c powder. Since lithium spinel is denser than the aluminate (3.61 versus 2.62 gms/cc), the presence of significant amounts of spinel can also increase green and sintered densities of whiteware made from the powder.

Summary (Refer to Tables I through X)

Aluminate

Lithium aluminate powders as received from Lithium Corporation of America are incompletely calcined, having residual alumina and lithium carbonate (up to 3 wt%). They have sub-stoichiometric lithium contents running from 8.2 to 9.2 wt% (theoretical composition is 10.53 wt% Li). Average particle size is 75 to 100 microns. The powders contain up to 7 wt% moisture and a variable mixture of the $\alpha$ and $\gamma$ allotropic modifications. The as-received powders contain a small amount of iron filings, possibly from a grinding process. They contain appreciable amounts of $LiAl_5O_8$ because of the low lithia contents.

Silicate

Lithium meta silicate powders as received from Lithium Corporation of America are incompletely calcined, having up to 1.5 wt% unreacted lithium carbonate and they have slight sub-stoichiometric lithium contents running from 14.8 to 15.0 wt% (theoretical composition is 15.43 wt% Li). The powders contain up to 4 wt% moisture and have the $Li_2SiO_3$ crystal structure. Average particle size is about 90 microns.

Zero-X

Zero-X pellets contain 2.2 wt% Li (2.27 wt% is theoretical), 135 ppm carbon (or 832 ppm unreacted $Li_2CO_3$), and about 105 ppm moisture. The pellets have a non-uniform hardness which makes them difficult to belt centerless grind to close tolerances. Pellet density is 1.83 gm/cc with an average pore size of 4 $\mu$.

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## Acknowledgements


Analytical works cited in this report were performed by:

Analytical Labs, BNW, under direction of W. L. Delvin - lithium, sulphur, fluorine, and water.

Chemical Development, BNW, J. H. Kleinpeter - mercury porosimetry.

Analytical Labs, DUN, under direction of G. B. Hansen - carbon, water.

Analytical Labs, Redox, Isochem, under direction of D. M. Creighton - lithium, isotopic.

Metallurgy Research, BNW, H. E. Kissinger - X-ray diffraction.

Ceramics Research, BNW, J. L. Bates - thermal conductivity of $LiAlO_2$.

Ceramics Research, BNW, C. E. McNeilly - differential thermal analysis of $LiAlO_2$.

Much of the information contained herein was obtained through discussion with personnel in BNW and GE-NRD. It was the interest of the author to collect and summarize the information into a form that will be most useful to those working with the materials.

TABLE I.

Chemical Summary

| | $LiAlO_2$ | | | | | $Li_2SiO_3$ | | Zero-X |
|---|---|---|---|---|---|---|---|---|
| Lot Number | 1 | 2 | 3a | 3b | 3c | 1 | 2 | |
| Total Carbon - ppm | 5230 | 2068 | 5438 | 3734 | 4066 | 2492 | 2317 | 135 |
| *Equivalent Carbonate - wt% | 3.22 | 1.28 | 3.35 | 2.30 | 2.50 | 1.54 | 1.43 | 0.083 |
| Lithium - wt% | 9.2 | 9.2 | 8.3 | 8.2 | 8.2 | 14.8 | 15.0 | 2.2 |
| Water - wt% | 6.0 | 6.9 | 0.3 | | | 1.5 | 3.7 | 0.0105 |
| Sulphur - ppm | | | | 300 | | | | |
| Fluorine - ppm | | | | <10 | | | | |
| Average Particle Size - microns | | 75 | 100 | | | | 90 | |
| Average Pore Size - microns | | | | | | | | 4 |
| Pellet Density - gm/cc | | | | | | | | 1.85 |
| % of Theoretical | | | | | | | | 77.1 |
| Approximate Bulk Density - gm/cc | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | |
| % of Theoretical | 42 | 42 | 42 | 42 | 42 | | 40 | |

Each lot number refers to a separate shipment from the supplier. Letter after number refers to separate containers in shipment.

*All carbon is assumed to be present as $Li_2CO_3$.

TABLE II.

Some Important Physical Constants

| | $LiAlO_2$ | $Li_2SiO_3$ | Zero-X |
|---|---|---|---|
| Melting Point - °C | above 1625° | 1201° | 1356° |
| True Density - gm/cc | *2.62(γ)<br>-3.38(α) | 2.52 | 2.4 |
| Thermal Expansion x $10^6$ °C | 12.4 (γ) | | 0.07 |
| Thermal Conductivity - $\frac{BTU}{ft^2 \cdot hr \cdot \frac{°F}{f+}}$ | approx 1.5 (α,γ) | | 0.967 |
| Theoretical Composition - wt% | | | |
| Li | 10.53 | 15.43 | 2.27 |
| $Li_2O$ | 22.7 | 33.2 | 4.9 |
| $Al_2O_3$ | 77.3 | | 16.6 |
| $SiO_2$ | | 66.8 | 78.5 |
| Compressive Strength - psi | | | 40,000 |
| Modulus of Rupture - psi | | | 55,000 |
| Safe Continuous Working Temperature - °C | | | 1260° |

*Latest X-ray density.[4,3] 2.55 is given in standard references. A brief conversion chart is given in Table XI.

TABLE II. (Continued)

Some Important Physical Constants

Heat and Free Energy of Formation of $LiAlO_2$ at 298°K.[10]

From Oxides

$\frac{1}{2}Li_2O(c) + \frac{1}{2}Al_2O_3 = LiAlO_2(c)$

$\Delta H_{298°K} = -12.95$ kcal/mole

$\Delta F_{298°K} = -13.6$ kcal/mole

From Elements

$Li(c) + Al(c) + O_2(g) = LiAlO_2(g)$

$\Delta H_{298°K} = -284.3$ kcal/mole

Entropy of $LiAlO_2$ at 298°K.[10]

$S_{298°K} = 12.75$ cal/mole-°K

Heat Capacity of $LiAlO_2$ from 298 to 1800°K.[11]

$Cp(\text{cal/mole-°K}) = 22.08 + 2.90 \times 10^{-3} T - 6.00 \times 10^{5} T^{-2}$

Heat Content of $LiAlO_2$ from 298 to 1800°K.[11]

$H_T - H_{298°K}(\text{cal/mole}) = 22.08T + 1.45 \times 10^{-3} T^2 + 6.00 \times 10^{5} T^{-1} - 8,724$

T = temperature in degrees Kelvin.

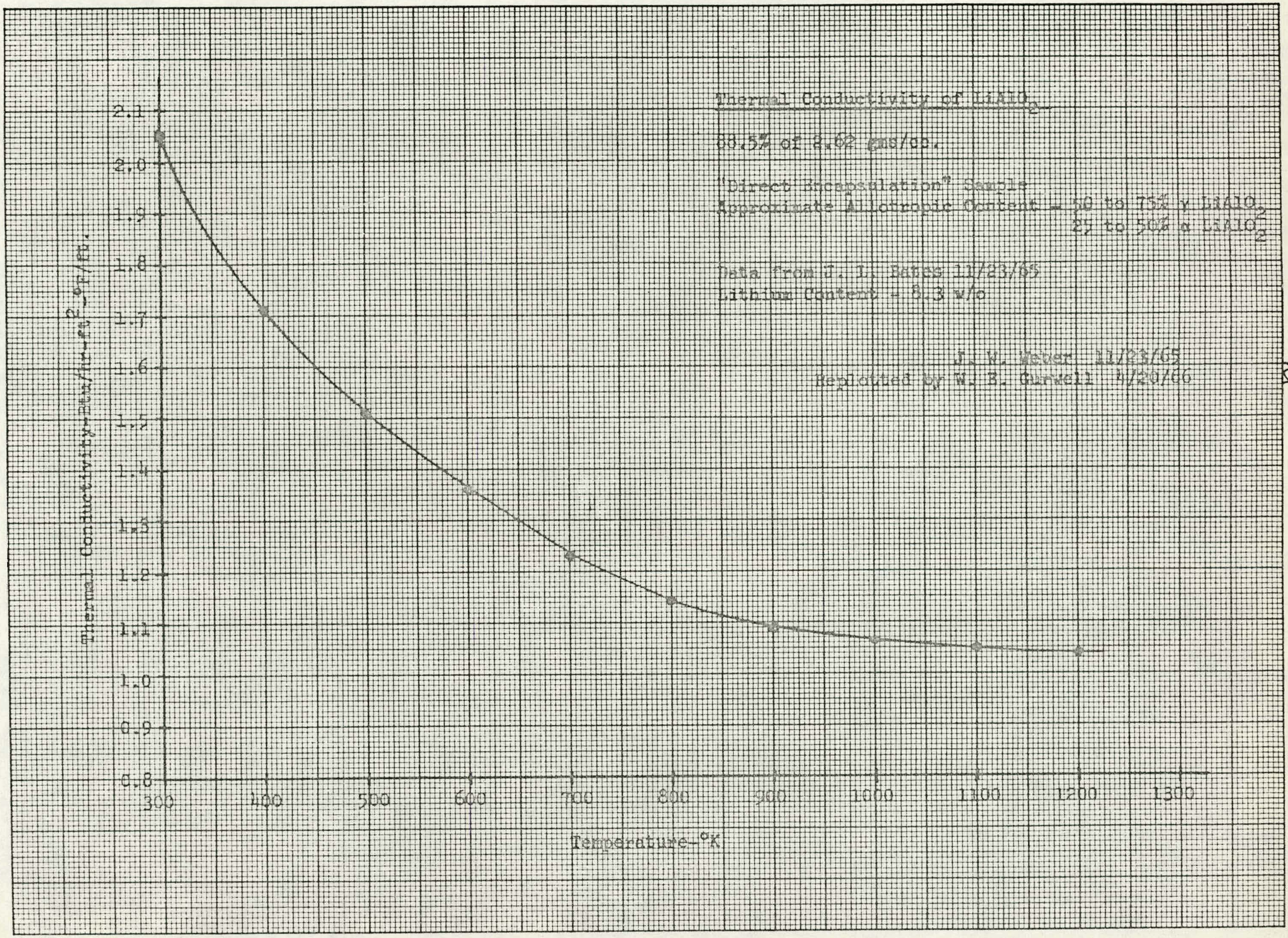

Thermal Conductivity of LiAlO2
88.5% of 2.62 gms/cc.
"Direct Encapsulation" Sample
Approximate Allotropic Content - 50 to 75% γ LiAlO2
25 to 50% α LiAlO2
Data from J. L. Bates 11/23/65
Lithium Content - 8.3 w/o
J. W. Weber 11/23/65
Replotted by W. B. Gurwell 4/20/66
Thermal Conductivity-Btu/hr-ft2 °F/ft.
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
300
400
500
600
700
800
900
1000
1100
1200
1300
Temperature-°K

TABLE III.

X-Ray Diffraction Data
for
As-Received Lithium Aluminate
Versus Literature Data

| Batch 2 $LiAlO_2$ As-Received from L.C.A. dÅ | I*/$I_1$ | Batch 3b $LiAlO_2$ As-Received from L.C.A. dÅ | I*/$I_1$ | α-$LiAlO_2$ (2) dÅ | I/$I_1$ | γ-$LiAlO_2$ (4) dÅ | I/$I_1$ |
|---|---|---|---|---|---|---|---|
| | | 5.23 | 20 | | | | |
| 4.84 | 40 | 4.73 | 100 | 4.8 | 90 | | |
| 4.26 | 60 | 4.15 | 20 | | | | |
| 4.02 | 90 | 3.98 | 40 | | | 3.99 | 100 |
| 3.78 | 20 | | | | | | |
| 3.67 | 20 | | | | | 3.65 | 14 |
| 3.50 | 10 | 3.48 | 10 | | | | |
| 3.17 | 35 | | | | | 3.15 | 23 |
| 2.78 | 85 | 2.67 | 50 | | | 2.68 | 65 |
| 2.60 | 100 | 2.58 | 50 | | | 2.58 | 73 |
| 2.50 | 15 | | | | | | |
| 2.40 | 25 | 2.38 | 50 | 2.40 | 55 | 2.39 | 2 |
| 2.23 | 10 | 2.21 | 10 | | | | |
| 2.17 | 10 | | | | | 2.17 | 8 |
| 2.09 | 15 | 2.08 | 10 ←α-$Al_2O_3$ | | | | |
| 2.01 | 25 | 2.00 | 100 | 2.01 | 100 | | |
| 1.90 | 10 | | | | | 1.94 | 2 |
| 1.87 | 20 | 1.86 | 10 | 1.86 | 15 | 1.86 | 16 |
| 1.83 | 10 | | | | | 1.83 | 8 |
| 1.82 | 10 | | | | | 1.81 | 8 |

TABLE III. (Cont.)

| Batch 2 $LiAlO_2$ As-Received from L.C.A. dÅ | $I^*/I_1$ | Batch 3b $LiAlO_2$ As-Received from L.C.A. dÅ | $I^*/I_1$ | $\alpha$-$LiAlO_2$ (2) dÅ | $I/I_1$ | $\gamma$-$LiAlO_2$ (4) dÅ | $I/I_1$ |
|---|---|---|---|---|---|---|---|
| 1.77 | 10 | 1.79 | 10 | | | | |
| | | 1.67 | 5 | | | 1.66 | 2 |
| 1.64 | 10 | | | | | 1.63 | 10 |
| 1.61 | 15 | 1.60 | 50 ← $\alpha$-$Al_2O_3$ | | | 1.625 | 5 |
| | | | | | | 1.58 | 10 |
| 1.57 | 15 | | | 1.56 | 60 | 1.57 | 14 |
| 1.51 | 40 | 1.51 | 5 | | | 1.51 | 50 |
| 1.44 | 30 | 1.43 | 5 | 1.44 | 70 | 1.44 | 1 |
| 1.40 | 25 | 1.39 | 40 | 1.41 | 70 | 1.40 | 7 |
| 1.38 | 10 | | | | | 1.38 | 2 |
| 1.34 | 15 | | | 1.35 | 55 | 1.34 | 21 |
| | | | | | | 1.30 | 42 |
| | | | | 1.18 | 20 | 1.29 | 21 |
| | | | | 1.16 | 55 | 1.27 | 4 |
| | | | | | | 1.25 | 2 |
| | | | | | | 1.23 | 14 |
| 1.22 | 10 | | | 1.21 | 20 | 1.22 | 29 |
| | | | | | | 1.20 | 4 |
| | | | | | | 1.19 | 13 |
| | | | | 1.18 | 20 | 1.18 | 6 |
| 1.15 | 10 | | | 1.16 | 55 | 1.16 | 4 |

TABLE III. (Cont.)

Crystal Structures:

$\alpha$ - $LiAlO_2$ (2) - Rhomobohedral of $NaHF_2$

a = 2.801 Å

c = 14.214 Å

Molecular Volume = 32.205 Å$^3$

$\gamma$-$LiAlO_2$ (4) - Tetragonal

a = 5.169 Å

c = 6.268 Å

*Estimated peak intensities

TABLE IV.

X-Ray Diffraction Data for As-Received Lithium Meta Silicate Versus Literature Data

| Lithium[5] Meta Silicate dÅ | $I/I_1$ | As Received from L.C.A. dÅ | $I/I^*_1$ |
|---|---|---|---|
| 4.70 | 100 | | |
| | | 4.25 | 3 |
| 4.02 | 10 | 4.00 | 11 |
| | | 3.91 | 7 |
| | | 3.34 | 11 |
| 3.32 | 22 | 3.30 | 100 |
| 2.72 | 74 | 2.70 | 64 |
| 2.66 | 13 | 2.66 | 13 |
| 2.35 | 19 | 2.32 | 44 |
| 2.10 | 5 | 2.09 | 10 |
| | | 1.82 | 10 |
| 1.78 | 10 | 1.76 | 11 |
| 1.66 | 12 | 1.65 | 10 |
| 1.57 | 30 | 1.56 | 14 |
| | | 1.47 | 6 |
| 1.36 | 6 | 1.35 | 10 |
| 1.30 | 12 | 1.30 | 13 |
| 1.26 | 8 | 1.25 | 3 |
| 1.18 | 5 | 1.17 | 4 |
| 1.14 | 5 | 1.13 | 3 |

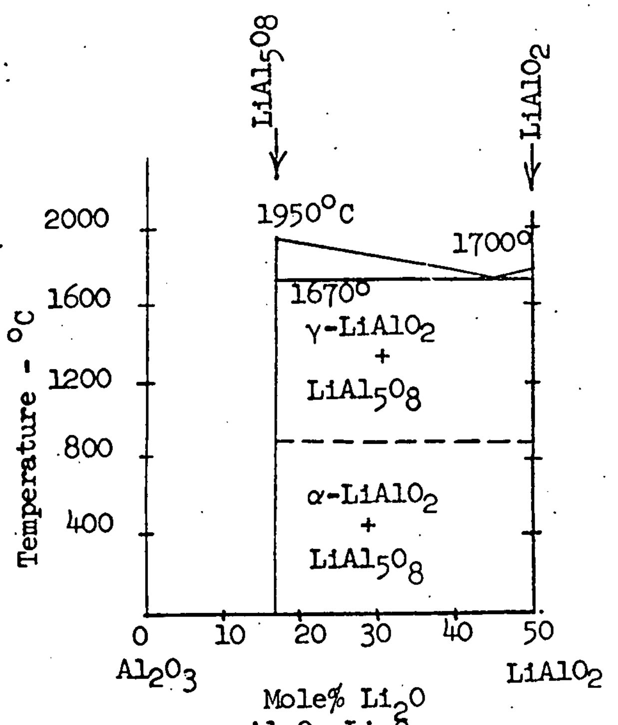
Crystal Structure: Rhombohedral

a = 1.58 c = 1.60

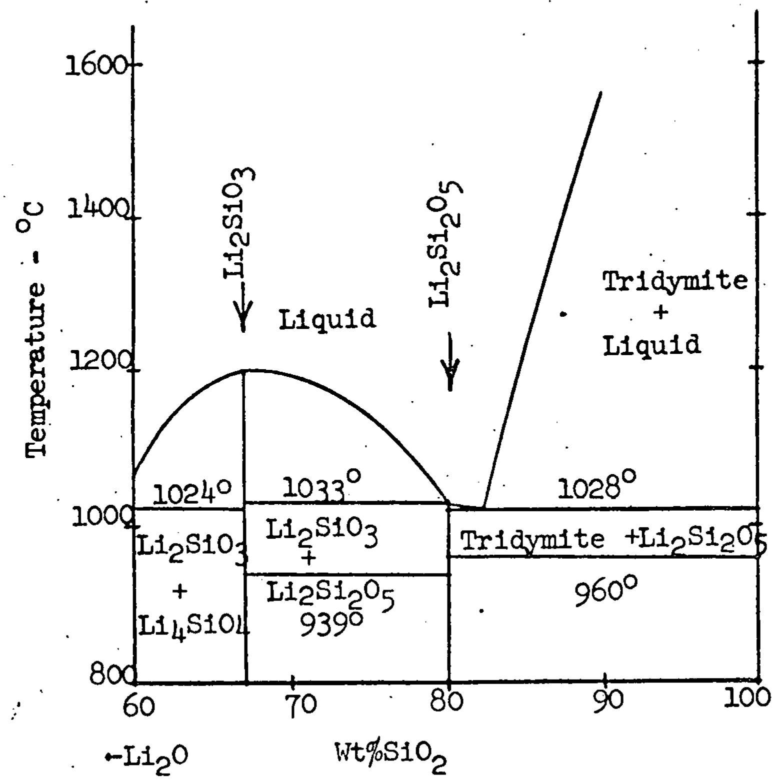
TABLE V.

X-Ray Diffraction Data for Zero-X Pellets versus Literature Data

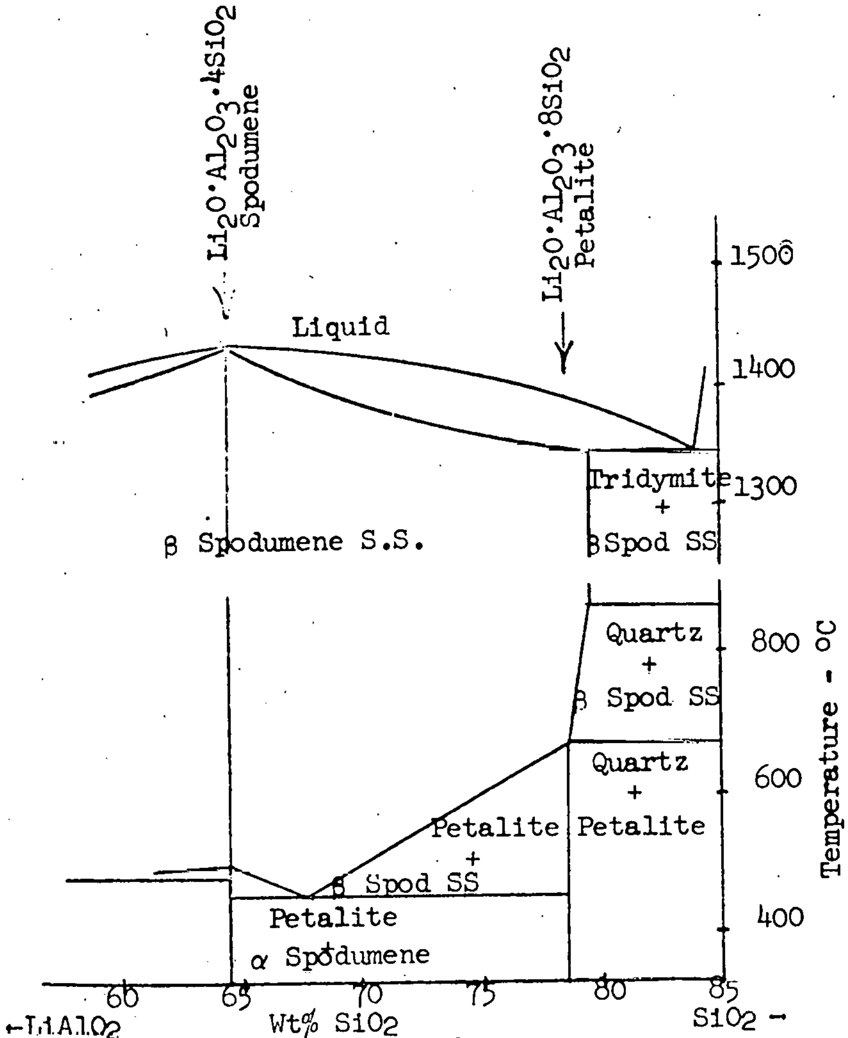
| Zero-X As Received from Ferro Corp. | | Australian Petalite Heated to 1350°C [5] | | Beta Spodumene [5] | |
|---|---|---|---|---|---|
| dÅ | $I/I_1$ | dÅ | $I/I_1$ | dÅ | $I/I_1$ |
| 5.75 | 20 | 5.78 | 30 | 5.82 | 30 |
| 4.55 | 30 | 4.57 | 50 | 4.61 | 50 |
| 3.88 | 60 | 3.87 | 60 | 3.92 | 60 |
| 3.45 | 100 | 3.46 | 100 | 3.49 | 100 |
| 3.14 | 40 | 3.14 | 50 | 3.17 | 50 |
| 2.62 | 10 | 2.62 | 30 | | |
| 2.28 | 20 | 2.29 | 40 | 2.30 | 40 |
| 2.24 | 20 | 2.26 | 10 | 2.26 | 40 |
| 2.10 | 20 | 2.10 | 40 | 2.11 | 40 |
| 1.92 | 20 | 1.92 | 50 | 1.94 | 50 |
| 1.87 | 60 | 1.87 | 60 | 1.88 | 60 |
| | | 1.86 | 60 | 1.87 | 60 |
| 1.64 | 20 | 1.63 | 40 | 1.65 | 40 |
| 1.53 | 20 | | | 1.54 | 20 |
| 1.42 | 20 | | | | |
| 1.40 | 20 | | | | |
| 1.37 | 20 | | | | |
| 1.34 | 20 | | | | |
| 1.32 | 5 | | | | |
| 1.31 | 5 | | | | |
| 1.23 | 10 | | | | |
| 1.18 | 10 | | | | |




$Al_2O_3$-$Li_2O$




$SiO_2$-$Li_2O$




$LiAlO_2$ - $SiO_2$

TABLE VI.

Phase Diagrams Concerning $LiAlO_2$, $Li_2SiO_3$, and Petalite (or Zero-X)

TABLE VII.

Spectrochemical Data

| Element | Thermal Cross Section | $LiAlO_2$ Batch 2 *2023 | Batch 3a 2318 | Batch 3b 2325 | Batch 3c 2326 | $Li_2SiO_3$ Batch 2 2025 | Zero-X 2317 |
|---|---|---|---|---|---|---|---|
| Ag | 63 | - | - | - | - | - | <T |
| Al | .23 | S | S | M-S | M-S | T-M | S |
| As | 4.3 | - | - | - | - | - | * |
| B | 755 | T | - | <T | <T | T | T-M |
| Cr | 3.1 | <T | <T | <T | <T | - | <T |
| Cu | 3.8 | T | <T | <T | T | T | T-M |
| Fe | 2.6 | M | T-M | T-M | T-M | M | M |
| Ga | 3.1 | M | M | M | M | - | - |
| Li | 71 | SS | S | S | S | SS | S |
| Mg | .06 | <T | <T | <T | <T | M | T-M |
| Mn | 13 | T | <T | <T | <T | <T | <T |
| Mo | 2.7 | <T | <T | - | - | - | <T |
| Na | .53 | M-S | M-S | M-S | M-S | M | T-M |
| Ni | 4.6 | <T | <T | <T | <T | <T | <T |
| Pb | .17 | <T | - | - | - | <T | - |
| Ru | 2.5 | - | - | - | - | - | - |
| Sb | 5 | - | - | - | - | <T | - |
| Si | .16 | M | T-M | T-M | M | S | S |
| Sn | .63 | - | - | T-M | T-M | * | - |
| Ti | 5.8 | M | M | T-M | M | T-M | T |
| V | 4.9 | <T | - | - | - | <T | - |
| W | 19 | - | - | - | - | - | - |
| Zr | .18 | * | - | - | - | - | - |

(Continued on next page)

TABLE VII. (Continued)

*Number refers to BNW Spectrochemical Laboratory plate number.

Symbol Meaning:

| | |
|---|---|
| SS | Major detectable constituent |
| S | Strong - greater than 1% |
| M | Moderate - 1% $\pm$ 00.01% |
| T | Trace - Less than 0.01% |
| - | Not detected |
| * | Interference |

Elements analyzed for but not detected in any of the above analyses are Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cs, Ge, Hf, Hg, In, Ir, K, La, Nb, Os, P, Pd, Pt, Pu, Rb, Re, Rh, Sc, Sr, Ta, Th, U, Y, Zn.

# The Tyler Standard Screen Scale

## Fourth Root of Two Series for Closer Sizing

Form No. L-8
Please mention above when ordering

L-8

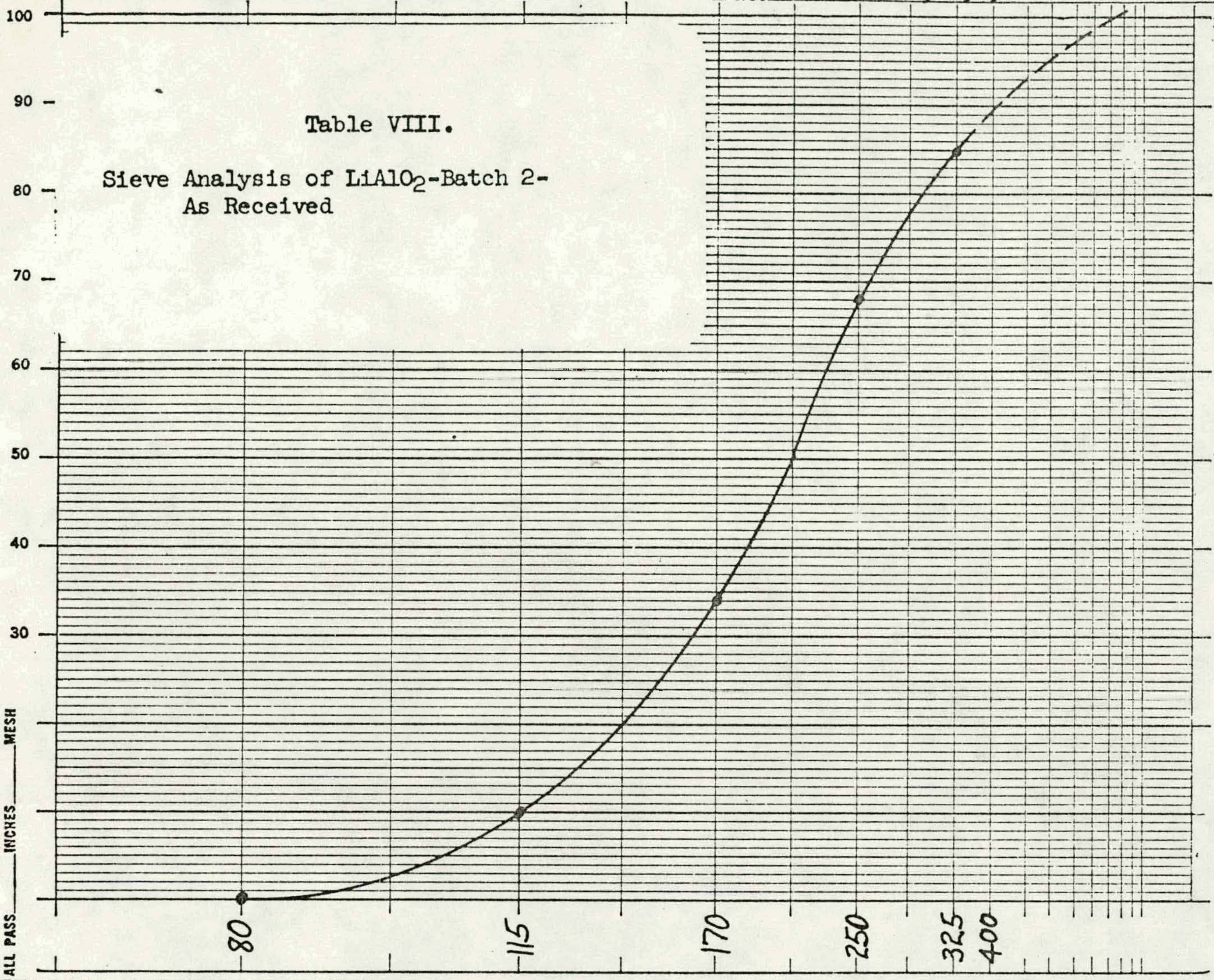
Cumulative Direct Diagram of Screen Analysis on Sample of $LiAlO_2$ - Batch 2 - As Received.

Name

Date June 11, 1965

Table VIII.

Sieve Analysis of $LiAlO_2$-Batch 2-
As Received




SCREEN SCALE RATIO 1.189

| Openings Inches | Openings Microns | Tyler Mesh | U. S. No. | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0195 | 500 | 32 | | | | | | | | | | |
| .0164 | 420 | 35 | | | | | | | | | | |
| .0138 | 350 | 42 | | | | | | | | | | |
| .0116 | 297 | 48 | | | | | | | | | | |
| .0097 | 250 | 60 | | | | | | | | | | |
| .0082 | 210 | 65 | | | | | | | | | | |
| .0069 | 177 | 80 | | | | 0.2 | | | | | | |
| .0058 | 149 | 100 | | | | | | | | | | |
| .0049 | 125 | 115 | | | | 9.9 | | | | | | |
| .0041 | 105 | 150 | | | | | | | | | | |
| .0035 | 88 | 170 | | | | 34.1 | | | | | | |
| .0029 | 74 | 200 | | | | | | | | | | |
| .0024 | 62 | 250 | | | | 68.2 | | | | | | |
| .0021 | 53 | 270 | | | | | | | | | | |
| .0017 | 44 | 325 | | | | 84.7 | | | | | | |
| .0015 | 37 | 400 | | | | | | | | | | |
| Pass | | | | | | 100.0 | | | | | | |
| | | | Totals, | | | 100.0 | | | | | | |



N PLOTTING SQUARE ROOT OF TWO SERIES USE EVERY OTHER VERTICAL LINE

THE W. S. TYLER COMPANY, CLEVELAND 14, OHIO, U.S.A. 7-63

# The Tyler Standard Screen Scale

Form No. L-8
Please mention above when ordering

## Fourth Root of Two Series for Closer Sizing

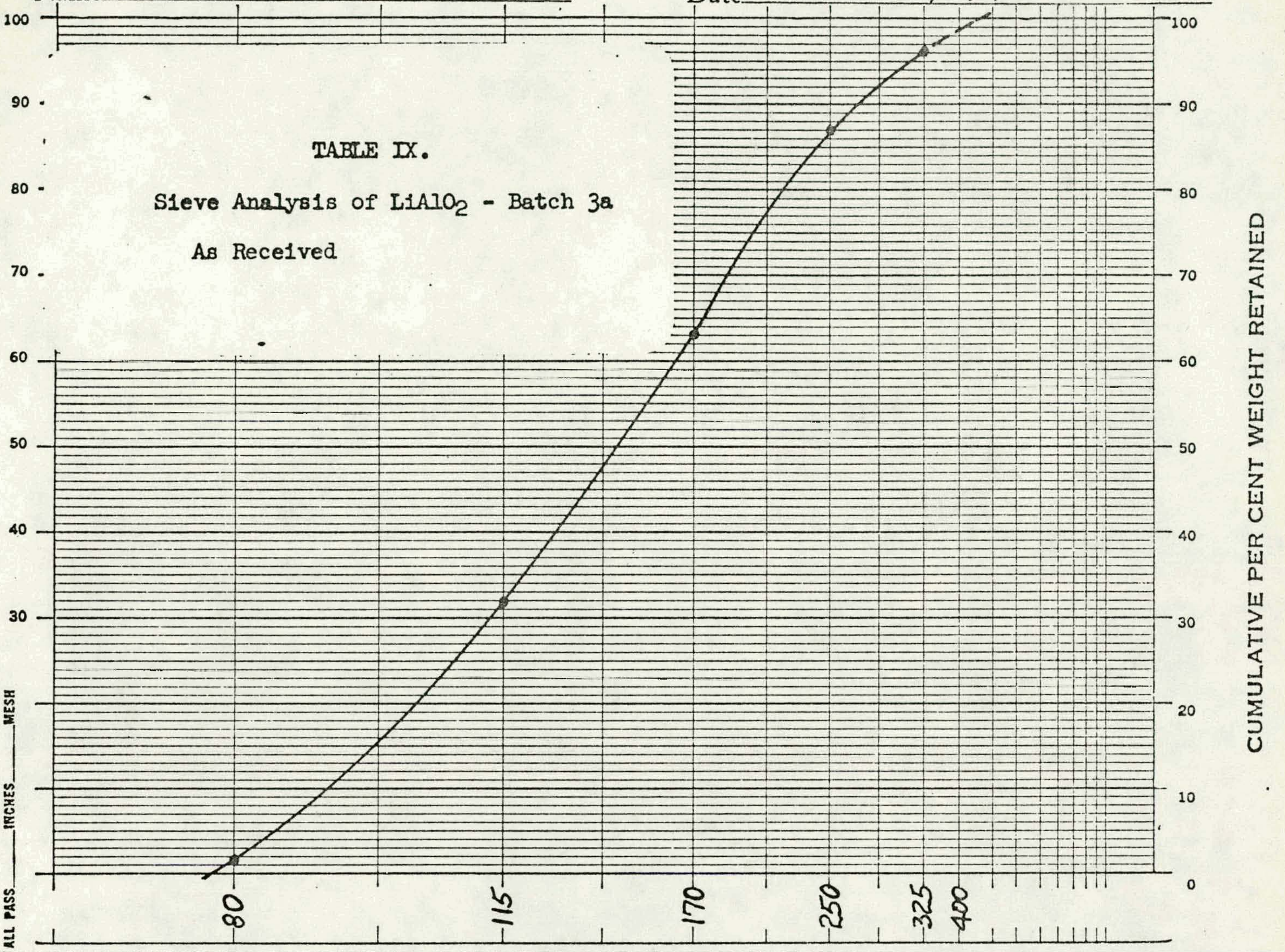
Cumulative Direct Diagram of Screen Analysis on Sample of ~~$LiAlO_2$ - Batch 3a - As Received.~~ L-8

Name________________ Date November 10, 1965

TABLE IX.

Sieve Analysis of $LiAlO_2$ - Batch 3a

As Received




| SCREEN SCALE RATIO 1.189 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Openings | | | | | | | | | | | | |
| Inches | ~~XXXX XXXX~~ Microns | Tyler Mesh | U. S. No. | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights |
| .0195 | 500 | 32 | | | | | | | | | | |
| .0164 | 420 | 35 | | | | | | | | | | |
| .0138 | 350 | 42 | | | | | | | | | | |
| .0116 | 297 | 48 | | | | | | | | | | |
| .0097 | 250 | 60 | | | | | | | | | | |
| .0082 | 210 | 65 | | | | | | | | | | |
| .0069 | 177 | 80 | | | | 1.7 | | | | | | |
| .0058 | 149 | 100 | | | | | | | | | | |
| .0049 | 125 | 115 | | | | 31.9 | | | | | | |
| .0041 | 105 | 150 | | | | | | | | | | |
| .0035 | 88 | 170 | | | | 63.3 | | | | | | |
| .0029 | 74 | 200 | | | | | | | | | | |
| .0024 | 62 | 250 | | | | 87.1 | | | | | | |
| .0021 | 53 | 270 | | | | | | | | | | |
| .0017 | 44 | 325 | | | | 96.2 | | | | | | |
| .0015 | 37 | 400 | | | | | | | | | | |
| Pass | | | | | | | | | | | | |
| | | | Totals, | | | 100.0 | | | | | | |

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IN PLOTTING SQUARE ROOT OF TWO SERIES USE EVERY OTHER VERTICAL LINE

THE W. S. TYLER COMPANY, CLEVELAND 14, OHIO, U.S.A. 7-63

Form No. L-8
Please mention above when ordering

# The Tyler Standard Screen Scale

## Fourth Root of Two Series for Closer Sizing

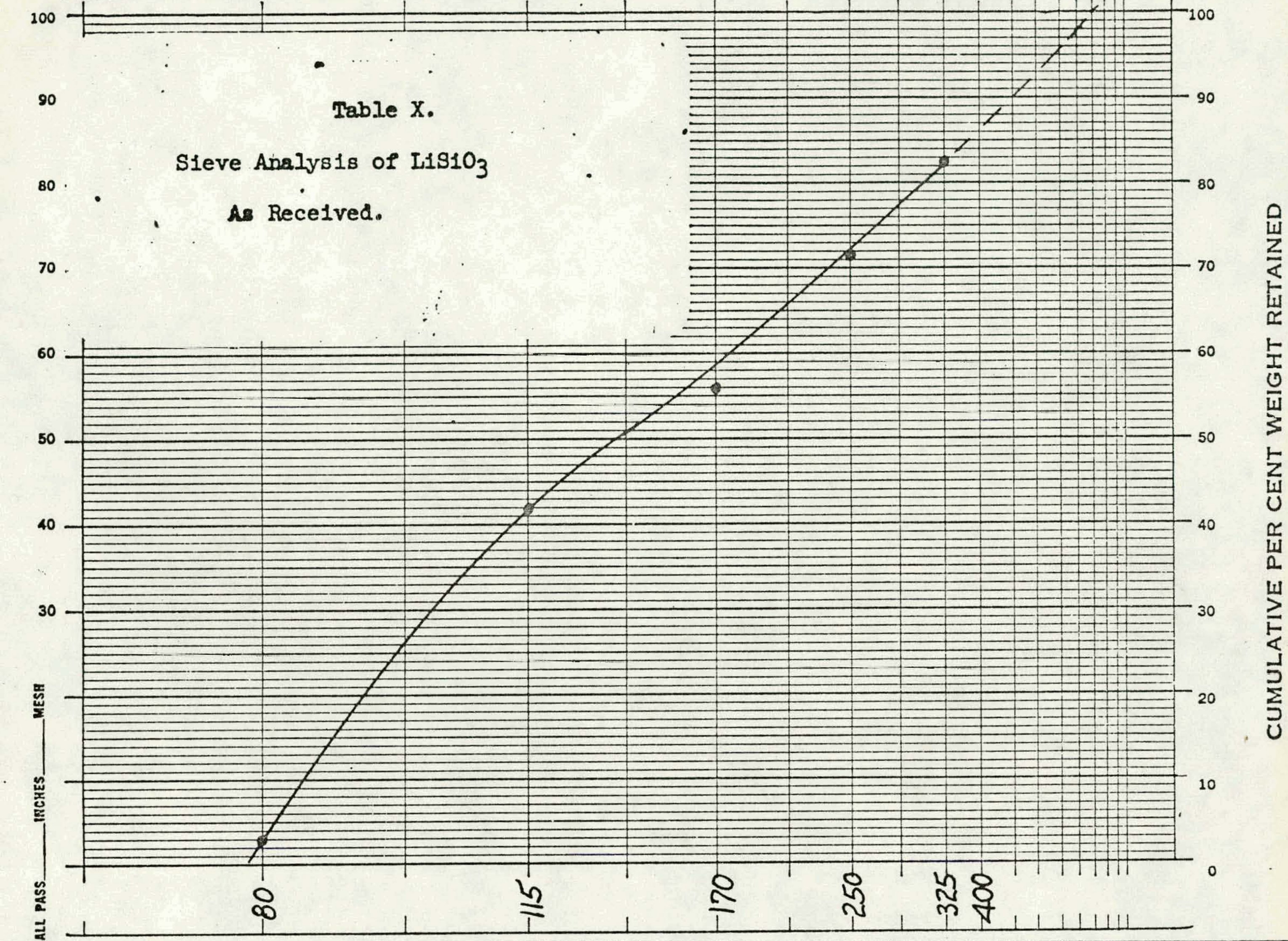
Cumulative Direct Diagram of Screen Analysis on Sample of $Li_2SiO_3$ - Batch 2 - As Received L-8

Name ______ Date June 11, 1965

**Table X.**

Sieve Analysis of $LiSiO_3$

As Received.




SCREEN SCALE RATIO 1.189

| Openings Inches | Openings Microns | Tyler Mesh | U. S. No. | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0195 | 500 | 32 | | | | | | | | | | |
| .0164 | 420 | 35 | | | | | | | | | | |
| .0138 | 350 | 42 | | | | | | | | | | |
| .0116 | 297 | 48 | | | | | | | | | | |
| .0097 | 250 | 60 | | | | | | | | | | |
| .0082 | 210 | 65 | | | | | | | | | | |
| .0069 | 177 | 80 | | | | 3 | | | | | | |
| .0058 | 149 | 100 | | | | | | | | | | |
| .0049 | 125 | 115 | | | | 42 | | | | | | |
| .0041 | 105 | 150 | | | | | | | | | | |
| .0035 | 88 | 170 | | | | 56 | | | | | | |
| .0029 | 74 | 200 | | | | | | | | | | |
| .0024 | 62 | 250 | | | | 71.5 | | | | | | |
| .0021 | 53 | 270 | | | | | | | | | | |
| .0017 | 44 | 325 | | | | 82.5 | | | | | | |
| .0015 | 37 | 400 | | | | | | | | | | |
| Pass | | | | | | | | | | | | |
| | | | Totals, | | | 100.0 | | | | | | |

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TABLE XI.

Conversion of Percent Theoretical Densities for Lithium Aluminate 2.55 gm/cc Base to More Realistic 2.62 gm/cc Base

| Density - gm/cc | % Theoretical 2.55 | Density 2.62 |
|---|---|---|
| 1.275 | 50.0 | 48.7 |
| 1.31 | 51.3 | 50.0 |
| 1.53 | 60.0 | 58.4 |
| 1.571 | 61.6 | 60.0 |
| 1.785 | 70.0 | 68.1 |
| 1.834 | 71.9 | 70.0 |
| 1.911 | 75.0 | 73.0 |
| 1.964 | 77.0 | 75.0 |
| 2.04 | 80.0 | 77.8 |
| 2.094 | 82.2 | 80.0 |
| 2.168 | 85.0 | 82.7 |
| 2.227 | 87.3 | 85.0 |
| 2.292 | 90.0 | 87.6 |
| | 92.5 | 90.0 |
| 2.422 | 95.0 | 92.5 |
| | 97.6 | 95.0 |
| 2.55 | 100.0 | 97.4 |
| 2.62 | 102.6 | 100.0 |