NASA TECHNICAL NOTE

NASA TN D-5505

IONIC CONDUCTIVITY OF LANTHANUM FLUORIDE

by William L. Fielder

Lewis Research Center
Cleveland, Ohio

1. Report No. NASA TN D-5505	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle IONIC CONDUCTIVITY OF LANTHANUM FLUORIDE		5. Report Date October 1969
		6. Performing Organization Code
7. Author(s) William L. Fielder		8. Performing Organization Report No. E-5108
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		10. Work Unit No. 120-34
		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Note
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The electrical conductivities of lanthanum fluoride single crystals containing from 0.02 to 0.15 mole percent calcium ion impurities were measured between 25° and 740° C. The intrinsic specific conductivity K in ohm^{-1}-cm^{-1} of lanthanum fluoride is

$$K = \left(\frac{7\pm1\times10^5}{T}\right)\exp\left(-\frac{19\ 100\pm300}{RT}\right)$$

where T is the absolute temperature and R is the gas constant. The activation energies for the formation of Schottky defects and for the migration of fluoride ion vacancies are 46 and 7.6 kcal/mole (192 and 32 kJ/mole), respectively. Mechanisms are proposed for the fluoride ion conduction process in lanthanum fluoride.

17. Key Words (Suggested by Author(s)) Ionic conductivity Lanthanum fluoride	18. Distribution Statement Unclassified - unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 16	22. Price* $3.00

IONIC CONDUCTIVITY OF LANTHANUM FLUORIDE

by William L. Fielder

Lewis Research Center

SUMMARY

The electrical conductivities of lanthanum fluoride single crystals were measured between 25° and 740° C. The experimental activation energies were calculated from the slopes of the plots of the logarithms of the products of the specific conductivity and the absolute temperature against the reciprocals of the absolute temperatures.

The specific conductivity K in ohm^{-1}-centimeter^{-1} of single crystals of lanthanum fluoride in the high-temperature intrinsic region is

$$K = \left(\frac{7 \pm 1 \times 10^5}{T}\right) \exp\left(-\frac{19\ 100 \pm 300}{RT}\right)$$

where T is the absolute temperature and R is the gas constant. The following mechanism is proposed for the conductivity process for this region: (1) thermal formation of lanthanum and fluoride ion vacancies by the Schottky mechanism with an activation energy of about 46 kilocalories per mole (192 kJ/mole); and (2) migration of fluoride ions with a migration energy of about 7.6 kilocalories per mole (32 kJ/mole).

For the extrinsic region, the defects responsible for the conduction are formed by impurities. The following mechanism is proposed for the conductivity process for the straight line portion of this extrinsic region: (1) formation of fluoride ion vacancies by introduction of calcium ions into the lattice and (2) migration (with an activation energy of about 7.6 kcal/mole or 32 kJ/mole) of the fluoride ions through these vacancies.

At the lower portion of the extrinsic region, the activation energy increased. This increase is proposed to be a result of precipitation of the calcium ion impurities or of complexing of fluoride ion vacancies.

INTRODUCTION

Many of the previous investigations concerned with the ionic conductivity of solids have dealt with the halides of group IA (alkali metals) and IB (copper and silver) (ref. 1). All of these halides are cationic conductors. Group II fluorides have also been investigated (refs. 2 to 4). In contrast, these compounds are anionic conductors.

Lanthanum fluoride is of particular interest since its mechanism of conductivity may be representative of many ionic trivalent halides. Furthermore, the one previous investigation of its conductivity yielded some surprising results (ref. 5). For example, an experimental activation energy of only about 2 kilocalories per mole (8 kJ/mole) was reported for the data above 160° C. This energy is comparable with values for diffusional processes in the liquid state. The only other solid materials that have such low activation energies are certain silver compounds, α-silver iodide, (α-AgI), silver sulfur iodide (Ag_3SI), or silver rubidium iodide (Ag_4RbI_5), in which the silver ion is mobile. For example, the activation energies for α-AgI (ref. 6) and Ag_4RbI_5 (ref. 7) are about 1.2 and 3.0 kilocalories per mole (5 and 13 kJ/mole), respectively.

The present investigation was undertaken to elucidate more fully the energetics and mechanisms for fluoride ion conduction. Measurements were made of the conductivities of lanthanum fluoride single crystals between 25° and 740° C. The activation energies and preexponential factors were calculated from the specific conductivities and their variations with temperature. Mechanisms consistent with the data are proposed for the conduction processes.

EXPERIMENT

Crystal Preparation

Three lanthanum fluoride single crystals (designated 1, 2, and 3) were obtained in sealed containers as 1-centimeter cubes from a commercial source. These crystals had been prepared by the Stockbarger technique (ref. 8). In this case, an atmosphere of gaseous hydrogen fluoride surrounded the crystals during growth. This atmosphere was used in an attempt to reduce the contamination of the crystals with oxide ions. Emission spectrographic analyses of crystals 1 and 3 are given in table I. The primary impurities in both crystals were calcium ions. Unfortunately, crystal 2 was inadvertently destroyed. Therefore, no analytical data could be obtained for crystal 2.

All manipulations of the crystals were carried out in a dry box that was continually purged with gaseous nitrogen obtained as boiloff from liquid nitrogen.

Any surface irregularities of the crystals were removed by grinding and polishing on fine emery paper. After the crystals were polished, they were colorless and transparent and contained no internal flaws visible to the eye. The dimensions of the crystals were determined with a micrometer.

Three methods were used to apply electrical contacts to the crystal faces in an attempt to minimize surface contact resistance. These methods were (1) sputtering with platinum, (2) sputtering with gold, and (3) painting with several thin coats of an emulsion of colloidal graphite in dry alcohol.

Temperature Control and Measurement

A three-heat-zone furnace was used. Each zone was controlled to $\pm 0.25^o$ C by means of a saturable-core reactor in conjunction with a proportional control unit. The temperatures of both electrodes were determined. These two temperatures usually did not differ by more than 0.2^o to 0.4^o C, and the temperature of the crystal was taken as the average of these readings. The measurements were made by means of platinum - platinum-13-percent-rhodium thermocouples that had been calibrated to provide an accuracy within at least 0.2^o to 700° C.

Resistivity Measurements

Essentially, the same apparatus and procedure that had been used to determine the conductivities of the alkaline earth fluorides (refs. 3 and 4) were used in this study. The crystal was preheated to 100° to 250° C in vacuum (mercury diffusion pump) for 4 to 8 hours in an attempt to remove oxygen, absorbed water, and other volatile contaminants, and then it was cooled slowly to room temperature. Helium gas that had been purified by passage over copper turnings at 375° C was added slowly through two liquid-nitrogen traps to a system pressure of about 700 millimeters of mercury (93 kN/m^2). Periodically, the system was reevacuated to counteract slight leakage or degassing of oxygen and water vapors.

Resistance measurements were made by the alternating-current method at 0.1, 1, 10, and 100 kilohertz with an impedance comparator bridge and standard resistors. The measured resistance of the crystal consists of two resistances in series: (1) the true crystal resistance and (2) the contact resistance at the crystal-electrode surface. This contact resistance is usually small depending on the type of electrode and the quality of the contact between the electrode and the crystal. This contact resistance was negligible for all the surface contacts below 550° C at the higher frequencies of 1, 10, and

100 kilohertz. However, for 0.1 kilohertz, this contact resistance was 5 to 9 percent. Above 550° C, the contact resistance of the sputtered platinum and gold surfaces increased to such an extent that these contacts were completely unsatisfactory. The graphite surface coatings, on the other hand, were satisfactory to the highest temperature used (740° C). The reason for the increased contact resistance of the metal surfaces above 550° C is not known.

RESULTS

For each lanthanum fluoride crystal, the logarithms of the products of the specific conductivity and the absolute temperature were plotted against the reciprocals of the absolute temperatures. The plot for crystal 1 is shown in figure 1. The conductivity of the higher temperature region, designated as the intrinsic region I, is that for the "pure" crystal. This intrinsic conductivity can be expressed by an equation of the form

$$\log K_I = \log\left(\frac{A_I}{T}\right) - \frac{\Delta E_I}{2.3026\ RT} \tag{1}$$

where

K_I intrinsic specific conductivity, ohm^{-1}-cm^{-1}

A_I intrinsic preexponential factor, ohm^{-1}-cm^{-1}

T absolute temperature, K

ΔE_I intrinsic experimental activation energy, kcal/mole; kJ/mole

R gas constant

The data for the intrinsic region for crystals 1 and 3 between about 380° and 740° C are plotted in figure 2. The slope and intercept of this line were determined by the method of least squares from which the experimental activation energy, the preexponential factor, and their standard deviations were obtained. The specific conductivity of "pure" lanthanum fluoride can be expressed as

$$K_I = \frac{7\pm1\times10^5}{T}\ \exp\left(-\frac{19\ 100\pm300}{RT}\right) \tag{2}$$

In figure 1, the lower temperature region, designated as the extrinsic region E, is the impurity controlled region. If the number of free defects (formed by the impurities in the crystal) remains constant over this extrinsic temperature range, the data should

lie on one straight line. However, if the number of free defects decreases, the data for the entire extrinsic region may not lie on a single straight line but may curve below it at the lower temperatures. The plots for all three of the lanthanum fluoride crystals indicated that a decrease in the number of free defects does occur. An example of this decrease is shown in figure 3 for crystal 1. The curvature for crystal 1 is quite small above 120° C. Therefore, the data have been fitted to one straight line from 360° to about 120° C. Below about 120° C, the slope of the line increases. Similar results were obtained for crystals 2 and 3. For these cases, the data were fitted to one straight line between 500° and about 125° C for crystal 2 (fig. 4) and between 500° and about 175° C for crystal 3 (fig. 5). As for figure 2, the slopes of the straight line portion of these extrinsic regions were determined by the method of least squares. The values for the experimental activation energies, the preexponential factors, and their standard deviations are listed in table II. An average value of 7.6±0.2 kilocalories per mole (32 kJ/mole) was obtained for the activation energy in the extrinsic region.

The slopes for the lower portion of the extrinsic regions cannot be obtained with certainty. However, near room temperature the slopes do appear to reach a constant value, from which an apparent activation energy of about 10 kilocalories per mole (42 kJ/mole) was calculated.

Results obtained in a previous investigation (ref. 5) contrasted sharply with the present data for the intrinsic region. For example, an apparent activation energy of only about 2 kilocalories per mole (4 kJ/mole) was reported for the conductivity data above 160° C. On the other hand, the results of the previous and present investigations agreed more closely at lower temperatures. For example, the previous investigation reported an energy of about 11 kilocalories per mole (46 kJ/mole) near room temperature (ref. 5). This result compares favorably with the value of about 10 kilocalories per mole (42 kJ/mole) that was obtained in the present investigation.

DISCUSSION

Ions migrate through point defects in real crystals. The thermal formation of such point defects is believed to occur through the Schottky or Frenkel mechanism. The Schottky process (fig. 6(a)) involves movement of cations and anions from their normal lattice sites to the surface and leaves vacancies of both species. In the Frenkel process (fig. 6(b)), an ion moves from its normal site to an interstitial position and leaves a vacancy. Therefore, for the Schottky process, the bulk volume of the crystal expands faster than the unit cell volume as the crystal temperature increases. On the other hand, for the Frenkel process, these volume changes are comparable.

For lanthanum fluoride, nuclear magnetic resonance (F^{19}) investigations show that fluoride ions are the migrating species (ref. 5). Further, since thermal expansion measurements (by dilatometer and X-ray diffraction) indicated that the bulk volume expanded faster than the unit cell volume, the thermal formation of point defects in lanthanum fluoride was assumed to occur primarily by the Schottky process (ref. 5).

The specific conductivity of lanthanum fluoride crystals K in ohm^{-1}-$centimeter^{-1}$ is related to the total number of fluoride ion vacancies n_T and to their mobility μ_F as follows:

$$K = en_T\mu_F \tag{3}$$

In the intrinsic region, the number of fluoride ion vacancies produced thermally n is greater than the number of those produced by impurities n_x. Introducing the appropriate relation for n_T and μ_F (ref. 9) into equation (3) gives

$$K_I = e\left[\gamma BN \exp\left(-\frac{\Delta E_F}{4RT}\right)\right]\left[\frac{Ce\nu a^2}{kT} \exp\left(-\frac{\Delta E_M}{RT}\right)\right] \tag{4}$$

where

γB correction factor for formation of defects

N number of ions per cm^3

ΔE_F energy of formation, kcal/mole; kJ/mole

R gas constant

T temperature, K

C correction factor for mobility of defects

e electric charge

ν presentation frequency of fluoride ion at vacancy boundary (jump frequency), sec^{-1}

a distance between adjacent positions in lattice, cm

k Boltzmann constant

ΔE_M energy of migration, kcal/mole; kJ/mole

Equation (4) is rearranged to

$$K_I = (\gamma BC)\left(\frac{Ne^2\nu a^2}{kT}\right)\left[\exp\left(-\frac{\Delta E_F}{4RT}\right)\right]\left[\exp\left(-\frac{\Delta E_M}{RT}\right)\right] \tag{5}$$

which reduces to

$$K_I = \frac{A_I}{T} \exp\left(-\frac{\Delta E_I}{RT}\right) \tag{6}$$

where A_I and ΔE_I are the preexponential factor and the experimental activation energy for the intrinsic region, respectively. Equations (5) and (6) can be compared with equation (2), which describes the experimental results.

A value of 19.1 kilocalories per mole (80 kJ/mole) was obtained for the intrinsic activation energy for lanthanum fluoride. The migration energy of fluoride ion vacancies (discussed later in this section) is only about 7.6 kilocalories per mole (32 kJ/mole). Therefore, the energy of formation of the defects is $\Delta E_F = 4 (\Delta E_I - \Delta E_M) = 46$ kilocalories per mole (192 kJ/mole). For comparison, the energy for the formation of Schottky defects in sodium chloride is about 46 kilocalories per mole (192 kJ/mole) (ref. 10).

A value of about 3 was obtained for the correction factor γBC for lanthanum fluoride from the expressions for the intrinsic preexponential factor in equations (2) and (5). The values for the constants are N, 1.8×10^{22} centimeters^{-3}; a, 2.6×10^{-8} centimeter (ref. 5); e^2, 2.56×10^{-31} erg-second per ohm or 2.56×10^{-38} joule-second per ohm; k, 1.38×10^{-6} erg per degree or 1.38×10^{-13} joule per degree; and ν, 8×10^{12} seconds^{-1}. The jump frequency ν, taken as the Debye frequency, was estimated from the Debye temperature (ref. 11). This small value for the correction factor γBC contrasts sharply with values that have been obtained for other solids. For example, Mott and Gurney suggested a value of about 10^4 for sodium chloride (ref. 9). A value of about 3 was estimated for the mobility correction factor C from the data in the extrinsic region (discussed later in this section). Therefore, the correction factor for the defect formation process γB was concluded to be essentially 1. This correction factor contrasts with values of about 10^3 suggested for γB for sodium chloride (ref. 9).

It should be pointed out that the experimental results obtained in this investigation for the intrinsic region differ significantly from the results of Sher et al. (ref. 5). As mentioned previously, they obtained a value for the apparent energy of activation of about 2 kilocalories per mole (8 kJ/mole) for the upper temperature range, which is in contrast to the value of 19.1 kilocalories per mole (80 kJ/mole) obtained in this work. The reason for this difference is not obvious.

In addition to thermal production of ion vacancies, fluoride ion vacancies can also be formed by impurities. Divalent cation impurities can produce fluoride ion vacancies, and tetravalent cations can produce fluoride ions in the interstitial sites (fig. 6(c) and (d)). For the lanthanum fluoride crystals used in this work, the production of interstitials by impurities was assumed to be negligible since tetravalent cations were not

detected in the analysis of the crystals. On the other hand, calcium ions were present as an impurity.

For the extrinsic region (impurity controlled region), the number of vacancies produced by the calcium ions n_x was much larger than those vacancies produced thermally. Therefore, for the straight line portion of the extrinsic region, the specific conductivity K_E in ohm^{-1}-centimeter^{-1} can be approximated from equation (4) as
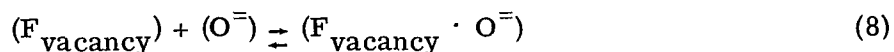
$$K_E = en_x \frac{Ce\nu a^2}{kT} \exp\left(-\frac{E_M}{RT}\right) \qquad (7)$$

This equation can be compared with the extrinsic preexponential factor and activation energy (given in table II) that describe the experimental results.

An estimate of the mobility correction factor C can be made from the preexponential factors and the various constants used before. About 3.6×10^{18} and 2.7×10^{19} fluoride ion vacancies per cubic centimeter were introduced into crystals 1 and 3, respectively, by the calcium ions. On this basis, a value for C of about 4 was obtained for crystal 1, and a value of about 2 was obatined for crystal 3. This difference in the value of C for the crystals is not significant. Accordingly, a value of 3 was assumed for the mobility correction factor. This value is of the same order of magnitude as that suggested for sodium chloride (ref. 9).

The experimental activation energy for the lanthanum fluoride crystals increased from 7.6 to about 10 kilocalories per mole (32 to 42 kJ/mole) for the temperature range below the straight line portion of the impurity controlled region. One could account for this apparent energy increase by assuming that the migration energy for fluoride ion vacancies increases with decreasing temperature in this region. This temperature dependence is not likely unless a change in the crystal lattice were to occur in this temperature range. Such is not the case. A more reasonable explanation is that the concentration of free fluoride ion vacancies, at these lower temperatures, decreases. This decrease in the number of free vacancies can arise by precipitation of the calcium ions or by complexing of vacancies. Both of these possibilities have been observed previously for alkali halides (ref. 12). For example, the presence of hydroxyl ions caused precipitation of magnesium ions, which had been added as a dopant to lithium fluoride (ref. 13). As a result, the apparent activation energy increased for the lower portion of the extrinsic region because of the removal of free lithium ion vacancies. A similar process may occur in lanthanum fluoride. If sufficient anions, such as hydroxyl or oxide ions, are present in the crystal, precipitation of the calcium ions may occur, which leads to an increased activation energy for the lower portion of the extrinsic region.

Complexing may also cause the activation energy to increase. For example, at lower temperatures in sodium chloride crystals containing divalent cations such as Cd^{++}, the sodium ion vacancies, which have a negative character, complex with the positive divalent cation of cadmium (ref. 14). This neutral complex will not contribute to the ionic conductivity. As a result, the conductivity decreases (as the number of free vacancies decreases) and this leads to an increase in the slope of the curve for the lower temperatures. A similar process may occur in lanthanum fluoride. Fluoride ion vacancies, having a positive character, may complex with a divalent anion to form a neutral species. Oxide ions, present in trace quantities, are the more likely source of such divalent anions. The complex may form as follows:

$$(F_{vacancy}) + (O^{=}) \rightleftarrows (F_{vacancy} \cdot O^{=}) \tag{8}$$

Future experimental investigations with lanthanum fluoride crystals containing known quantities of oxide or hydroxide ions, halide ions, and cations with a valence other than +3 will contribute to further understanding of this complexing process.

CONCLUDING REMARKS

The mechanism for the conductivity of lanthanum fluoride single crystals in the intrinsic region was proposed as follows: (1) formation of fluoride and lanthanum ion vacancies by the Schottky mechanism and (2) migration of the fluoride ions through these fluoride ion vacancies. For the impurity controlled (extrinsic) region, the fluoride vacancies were formed by the introduction of calcium ions into the lattice. Migration occurred, as before, through these fluoride ion vacancies. Finally, at the lower temperature portion of the extrinsic region, precipitation of the calcium ions or complexing between the fluoride ion vacancies and anion species may occur.

Lewis Research Center,
    National Aeronautics and Space Administration,
        Cleveland, Ohio, August 27, 1969,
            120-34.

REFERENCES

1. Brown, Frederick C.: The Physics of Solids. W. A. Benjamin, Inc., 1967.

2. Ure, Roland W., Jr.: Ionic Conductivity of Calcium Fluoride Crystals. J. Chem. Phys., vol. 26, no. 6, June 1957, pp. 1363-1373.

3. Fielder, William L.: Ionic Conductivity of Solid Barium Fluoride. NASA TN D-3346, 1966.

4. Fielder, William L.: Ionic Conductivity of Calcium and Strontium Fluorides. NASA TN D-3816, 1967.

5. Sher, A.; Solomon, R.; Lee, K.; and Muller, M. W.: Transport Properties of LaF_3. Phys. Rev., vol. 144, no. 2, Apr. 15, 1966, pp. 593-604.

6. Jost, Wilhelm: Diffusion in Solids, Liquids, Gases. Academic Press, 1960.

7. Owens, Boone B.; and Argue, Gary R.: High-Conductivity Solid Electrolytes: MAg_4I_5. Science, vol. 157, no. 3786, 1967, pp. 308-310.

8. Stockbarger, Donald C.: The Production of Large Artificial Fluorite Crystals. Disc. Faraday Soc., no. 5, 1949, pp. 294-299.

9. Mott, N. F.; and Gurney, R. W.: Electronic Processes in Ionic Crystals. Clarendon Press, Oxford, 1940.

10. Kittel, Charles: Introduction to Solid State Physics. John Wiley & Sons, Inc., 1953, p. 487.

11. Yen, W. M.; Scott, W. C.; and Schawlow, A. L.: Phonon-Induced Relaxation in Excited Optical States of Trivalent Praseodymium in LaF_3. Phys. Rev., vol. 136A, no. 1, Oct. 5, 1964, pp. 271-283.

12. Brown, N.; and Hoodless, I. M.: Ionic Conductivity in $NaCl-SrCl_2$ and $NaCl - BaCl_2$ Crystals, J. Phys. Chem. Solids, vol. 28, 1967, pp. 2297-2303.

13. Stoebe, Thomas G.: Influence of OH^- ions of Infrared Absorption and Ionic Conductivity in Lithium Fluoride Crystals. J. Phys. Chem. Solids, vol. 28, 1967, pp. 1375-1382.

14. Lidiard, A. B.: Ionic Conductivity of Impure Polar Crystals. Phys. Rev., vol. 94, no. 1, Apr. 1, 1954, pp. 29-37.

TABLE I. - EMISSION SPECTROGRAPHIC

ANALYSES OF LANTHANUM FLUO-

RIDE (MOLE PERCENT)

Element	Crystal	
	1	3
	Composition, mole %	
Lanthanum	Major component	Major component
Calcium	~ 0.02	0.15
Aluminum	$<.007$	$<.007$
Rare earths	(a)	(a)
Other	(a)	(a)

[a]Not detected.

TABLE II. - CONDUCTIVITY OF LANTHANUM

FLUORIDE IN STRAIGHT LINE PORTION

OF EXTRINSIC REGION

Crystal	Activation energy, ΔE_E		Preexponential factor, A_E $ohm^{-1}-cm^{-1}$
	kcal/mole	kJ/mole	
1	7.7 ± 0.1	32 ± 0.4	$1.4 \pm 0.1 \times 10^2$
2	7.8 ± 0.1	33 ± 0.4	$6.3 \pm 0.3 \times 10^2$
3	7.4 ± 0.2	31 ± 0.8	$4.6 \pm 0.3 \times 10^2$

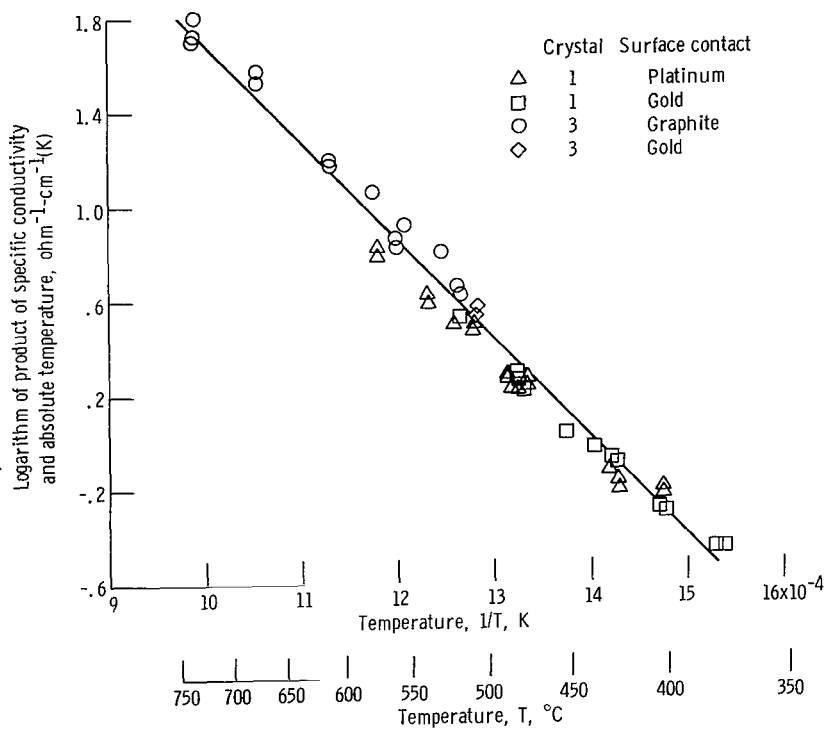Figure 1. - Specific conductivity of lanthanum fluoride crystal 1.

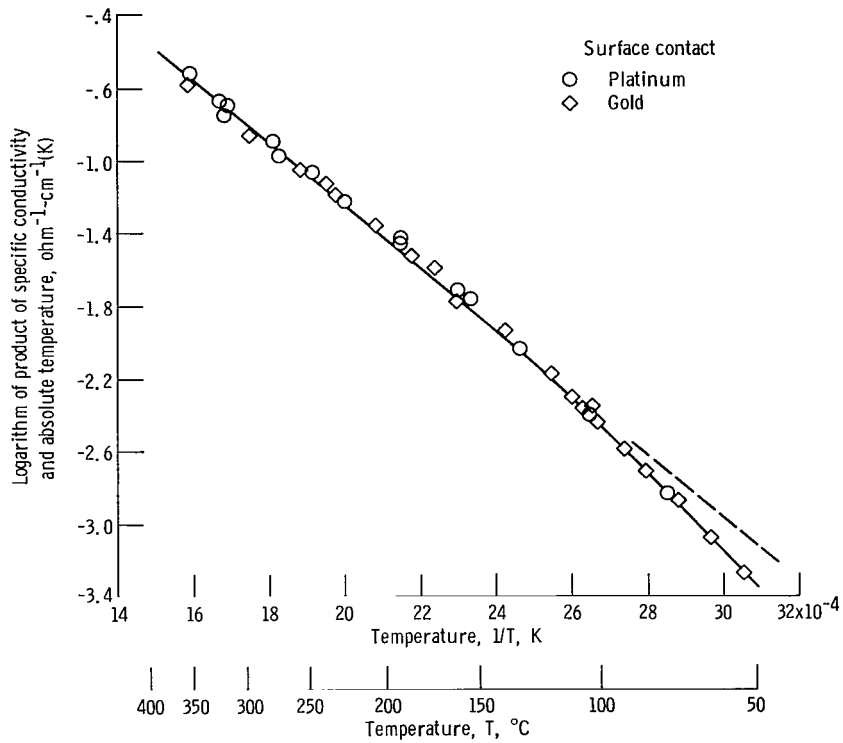Figure 2. - Specific conductivity of lanthanum fluoride in intrinsic region.

12

Figure 3. – Specific conductivity of lanthanum fluoride crystal 1 in impurity region.
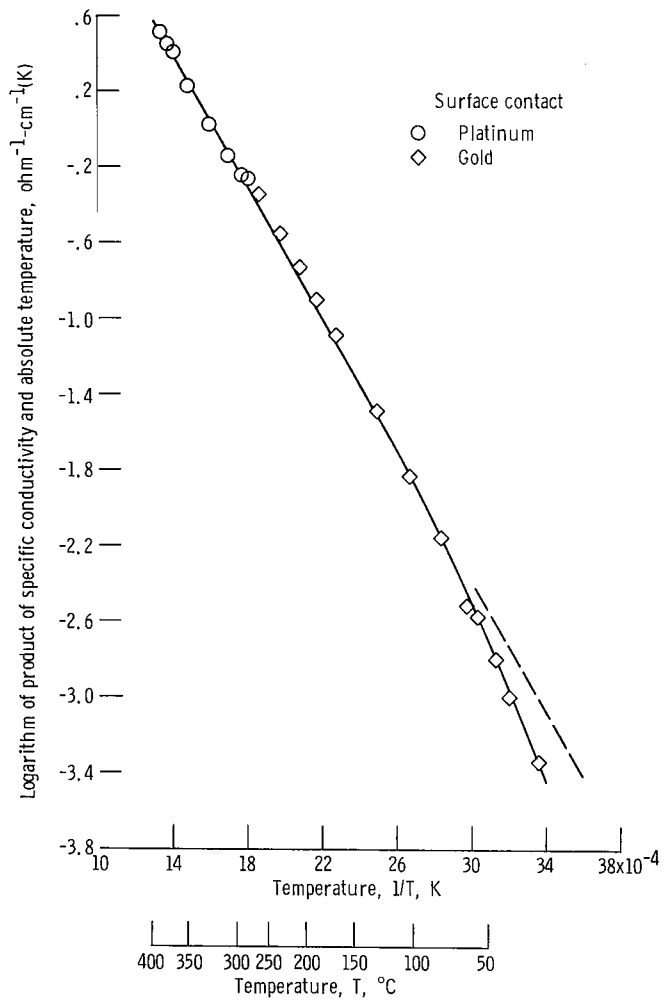
Figure 4. - Specific conductivity of lanthanum fluoride crystal 2 in impurity region.
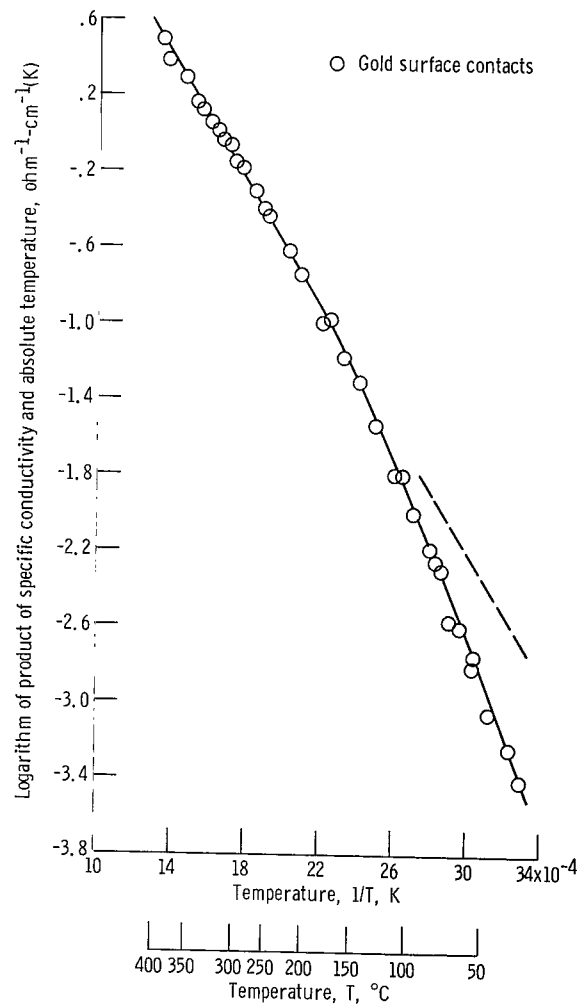

Figure 5. - Specific conductivity of lanthanum fluoride crystal 3 in impurity region.
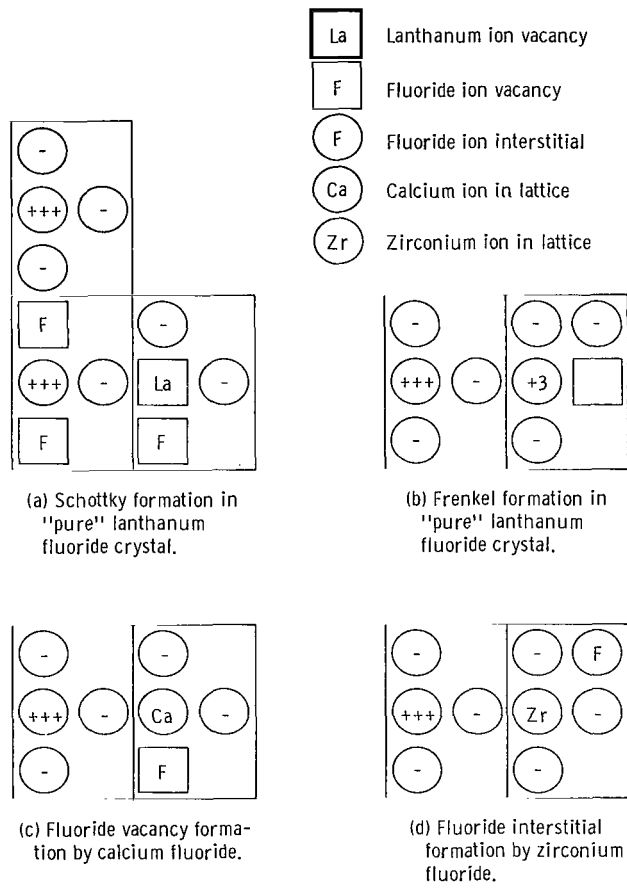
La — Lanthanum ion vacancy

F — Fluoride ion vacancy

F — Fluoride ion interstitial

Ca — Calcium ion in lattice

Zr — Zirconium ion in lattice

(a) Schottky formation in "pure" lanthanum fluoride crystal.

(b) Frenkel formation in "pure" lanthanum fluoride crystal.

(c) Fluoride vacancy formation by calcium fluoride.

(d) Fluoride interstitial formation by zirconium fluoride.

Figure 6. – Defects in lanthanum fluoride. (Sketches are only simple planar representations and are not intended to indicate structure of lanthanum fluoride.)

"*The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof.*"

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546