

# Molten Salts: Volume 4, Part 4

## Mixed Halide Melts

### Electrical Conductance, Density, Viscosity, and Surface Tension Data

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Data on the electrical conductance, density, viscosity, and surface tension of mixed halide melts have been systematically collected and evaluated. Results are given for eighty-five binary mixtures over a range of compositions and temperatures.

Key words: Bromides; chlorides; data compilation; density; electrical conductance; fluorides; halides; iodides; molten salt mixtures; standard reference data; surface tension; viscosity.

### Contents

	Page		Page
1. Introduction . . . . .	127	5.1. Fluorides-Chlorides . . . . .	130
2. Symbols and Units . . . . .	127	5.2. Fluorides-Bromides . . . . .	146
3. Experimental Methods . . . . .	127	5.3. Fluorides Iodides . . . . .	155
4. Treatment of Data . . . . .	128	5.4. Chlorides-Bromides . . . . .	164
4.1. Statistical Analysis . . . . .	128	5.5. Chlorides-Iodides . . . . .	244
4.2. Value Judgements . . . . .	129	5.6. Bromides-Iodides . . . . .	272
4.3. Physical Property Tables . . . . .	129	6. General Summary Tables . . . . .	292
4.4. Phase Diagrams . . . . .	130	7. Acknowledgements . . . . .	301
5. Mixed Halide Melts . . . . .	130	8. References . . . . .	301

### System Index

Fluoride-Chloride		Fluoride-Bromide	Page
	Page	CsF-CsBr . . . . .	146
BaF <sub>2</sub> -BaCl <sub>2</sub> . . . . .	130	KF-KBr . . . . .	148
BaF <sub>2</sub> -KCl . . . . .	131	LiF-LiBr . . . . .	151
CsF-CsCl . . . . .	132		
KF-BaCl <sub>2</sub> . . . . .	135	<b>Fluoride-Iodide</b>	
KF-KCl . . . . .	136	CsF-CsI . . . . .	155
KF-NaCl . . . . .	139	KF-KI . . . . .	157
LiF-LiCl . . . . .	140	LiF-LiI . . . . .	160
NaF-BaCl <sub>2</sub> . . . . .	144		
NaF-NaCl . . . . .	144	<b>Chloride-Bromide</b>	
RbF-RbCl . . . . .	145	AgCl-AgBr . . . . .	164
		AgCl-AlBr <sub>3</sub> . . . . .	168
		AgCl-KBr . . . . .	169

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	Page		Page
AgCl-LiBr	172	PbCl <sub>2</sub> -PbBr <sub>2</sub>	230
AgCl-NaBr	174	PbCl <sub>2</sub> -ZnBr <sub>2</sub>	234
AlCl <sub>3</sub> -NaBr	176	RbCl-AgBr	234
BiCl <sub>3</sub> -BiBr <sub>3</sub>	178	RbCl-KBr	234
CaCl <sub>2</sub> -KBr	178	RbCl-RbBr	237
CdCl <sub>2</sub> -CaBr <sub>2</sub>	179	TlCl-TlBr	239
CdCl <sub>2</sub> -CdBr <sub>2</sub>	179	ZnCl <sub>2</sub> -CdBr <sub>2</sub>	241
CdCl <sub>2</sub> -KBr	181	ZnCl <sub>2</sub> -PbBr <sub>2</sub>	243
CdCl <sub>2</sub> -NaBr	185		
CdCl <sub>2</sub> -PbBr <sub>2</sub>	185	<b>Chloride-Iodide</b>	
CdCl <sub>2</sub> -ZnBr <sub>2</sub>	186	AgCl-AgI	244
CsCl-AgBr	188	CdCl <sub>2</sub> -CdI <sub>2</sub>	245
CsCl-CsBr	188	CsCl-CsI	247
CsCl-KBr	192	CsCl-KI	251
CsCl-NaBr	192	HgCl <sub>2</sub> -HgI <sub>2</sub>	252
KCl-AgBr	193	KCl-CsI	253
KCl-AlBr <sub>3</sub>	197	KCl-KI	254
KCl-CaBr <sub>2</sub>	198	KCl-NaI	257
KCl-CdBr <sub>2</sub>	198	LiCl-LiI	261
KCl-CsBr	202	NaCl-KI	264
KCl-KBr	202	NaCl-NaI	267
KCl-NaBr	207	RbCl-RbI	269
KCl-PbBr <sub>2</sub>	210		
KCl-RbBr	210	<b>Bromide-Iodide</b>	
LiCl-AgBr	213	AgBr-AgI	272
LiCl-AlBr <sub>3</sub>	214	BiBr <sub>3</sub> -BiI <sub>3</sub>	273
LiCl-KBr	215	CsBr-CsI	273
LiCl-LiBr	215	HgBr <sub>2</sub> -HgI <sub>2</sub>	277
NaCl-AgBr	218	KBr-KI	278
NaCl-AlBr <sub>3</sub>	221	LiBr-LiI	280
NaCl-CdBr <sub>2</sub>	222	NaBr-NaI	284
NaCl-CsBr	222	RbBr-RbI	286
NaCl-KBr	223	SbBr <sub>3</sub> -SbI <sub>3</sub>	289
NaCl-NaBr	226	TlBr-TlI	291
PbCl <sub>2</sub> -CdBr <sub>2</sub>	229		
PbCl <sub>2</sub> -KBr	230		

## Phase Diagram Index

	Page		Page
BaF <sub>2</sub> -BaCl <sub>2</sub>	130	CdCl <sub>2</sub> -CdBr <sub>2</sub>	179
BaF <sub>2</sub> -KCl	131	CdCl <sub>2</sub> -KBr	181
KF-BaCl <sub>2</sub>	135	CsCl-CsBr	188
KF-KCl	136	CsCl-KBr	192
KF-NaCl	139	CsCl-NaBr	192
LiF-LiCl	140	KCl-AgBr	193
NaF-BaCl <sub>2</sub>	144	KCl-AlBr <sub>3</sub>	197
NaF-NaCl	144	KCl-CdBr <sub>2</sub>	198
RbF-RbCl	145	KCl-KBr	202
KF-KBr	148	KCl-NaBr	207
LiF-LiBr	151	KCl-PbBr <sub>2</sub>	210
KF-KI	157	LiCl-AgBr	213
LiF-LiI	160	LiCl-KBr	215
AgCl-AgBr	164	LiCl-LiBr	215
AgCl-AlBr <sub>3</sub>	168	NaCl-AgBr	218
AgCl-KBr	169	NaCl-CsBr	222
AgCl-LiBr	172	NaCl-KBr	223
AgCl-NaBr	174	NaCl-NaBr	226

	Page		Page
PbCl <sub>2</sub> -KBr	230	NaCl-KI	264
PbCl <sub>2</sub> -PbBr <sub>2</sub>	230	NaCl-NaI	267
AgCl-AgI	244	RbCl-RbI	269
CdCl <sub>2</sub> -CdI <sub>2</sub>	245	AgBr-AgI	272
CsCl-CsI	247	CsBr-CsI	273
HgCl <sub>2</sub> -HgCl <sub>2</sub> -I <sub>2</sub>	252	HgBr <sub>2</sub> -HgI <sub>2</sub>	277
KCl-KI	254	KBr-KI	278
KCl-NaI	257	NaBr-NaI	284
LiCl-LiI	261	SbBr <sub>3</sub> -SbI <sub>3</sub>	289

### 1. Introduction

The published data for the four physical properties: electrical conductance, density, viscosity, and surface tension for molten mixed halide systems have been reviewed and critically assessed, and the results, together with value judgements, are reported herewith. The collection and evaluation of molten salts data was undertaken as part of the NSRDS program in 1965. The physical properties were limited to the four most widely encountered in materials science and technology, viz., electrical conductance, viscosity, density, and surface tension; and the scope of the systems to inorganic compounds as "single-salt melts", i.e., one-component systems, and to binary mixtures of inorganic compounds. For a systematic approach, an anion classification was used to order the salts, and within each anion family an alphabetical order was followed for listing the salts by cationic constituent. The molten salts data series thus falls naturally into nine parts, as summarized in table I. The present publication is the seventh in this series [1-6]<sup>1</sup>, and completes the recommendations for binary mixtures of molten halides. The literature embraced is current to June, 1977.

TABLE I. NSRDS molten salts data series

(For single salts and their binary mixtures relative to the data for electrical conductance, viscosity, density and surface tension)

Molten salts	NSRDS recommendations	Ref.
Vol. 1 (1968)	Single salts ( $\kappa, \eta, \rho$ ) <sup>a</sup>	[1]
Vol. 2 (1969)	Single salts ( $\gamma$ ) <sup>a</sup>	[2]
Vol. 3 (1972)	Binary mixtures: nitrates, nitrites	[3]
Vol. 4, Pt. 1 (1974)	Binary mixtures of fluorides	[4]
Vol. 4, Pt. 2 (1976)	Binary mixtures of chlorides	[5]
Vol. 4, Pt. 3 (1977)	Binary mixtures: bromides, iodides	[6]
Vol. 4, Pt. 4	Binary mixtures: mixed halides <sup>b</sup>	
Vol. 5, Pt. 1	Binary mixtures: anion families <sup>c</sup> other than nitrates, nitrites, halides	
Vol. 5, Pt. 2	Additional binary mixtures <sup>c</sup>	

<sup>a</sup>Single Salt Updates: Some of the NSRDS recommendations advanced in 1968 and 1969 for single salt melts have been revised in the sequels. See the single-salts updates in Volumes 3-5, respectively, for information.

<sup>b</sup>Present work. Submitted for publication, July, 1977.

<sup>c</sup>Work in progress.

<sup>1</sup>Numbers in brackets refer to literature references in section 8.

The organization of the narrative and tabular data supporting the recommendations follows the style of the preceding parts of the series. Observations concerning melt preparation and purification are given; the temperature-liquidus phase diagram is included where possible. This material is followed by a tabular summary of the investigations critically examined (with temperature and concentration ranges, and comments on cell materials and method of calibration). Table(s) of recommended numerical values complete the presentation. The preceding analysis was developed for each of the four properties. Summary tables have been compiled to provide a total overview of the investigations, and are at the end of the manuscript.

### 2. Symbols and Units

The symbols and units<sup>2</sup> for the four physical properties in this compilation are:

$\kappa$  = specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

$\rho$  = density ( $\text{g cm}^{-3}$ )

$\eta$  = viscosity (cp)

$\gamma$  = surface tension ( $\text{dyn cm}^{-1}$ ).<sup>3</sup>

In addition:

E = activation energy ( $\text{cal mol}^{-1}$ )

$\Lambda$  = equivalent conductance ( $\text{ohm}^{-1} \text{cm}^2 \text{equiv}^{-1}$ )

C = concentration (mol %)

R = gas constant =  $1.98717 \text{ cal mol}^{-1} \text{K}^{-1}$

T = temperature in kelvins, defined on the thermodynamic scale by assigning 273.16 K to the triple point of water (freezing point, 273.15 K = 0 °C)

### 3. Experimental Methods

Practical aspects of molten salts containment (materials) and designs of experimental assemblies for measurements of electrical conductivity, viscosity, density, and surface tension have been reviewed in the preceding parts of this series. A summary is given in table II. In table III, an analysis of the use of the various techniques in the studies of mixed halides is given.

<sup>2</sup>For conversion to the SI system:

$$1 \text{ ohm}^{-1} \text{cm}^{-1} = 1 \times 10^2 \Omega^{-1} \text{m}^{-1}$$

$$1 \text{ g cm}^{-3} = 1 \times 10^{-3} \text{Kg cm}^{-3}$$

$$1 \text{ cp} = 1 \times 10^{-3} \text{N s m}^{-2}$$

$$1 \text{ dyn cm}^{-1} = 1 \times 10^{-3} \text{N m}^{-1}$$

$$1 \text{ cal mol}^{-1} = 4.184 \text{ J mol}^{-1}$$

<sup>3</sup>When  $\gamma$  is treated as a free energy per unit area, it is given the unit,  $\text{erg cm}^{-2}$ ; this is dimensionally identical to  $\text{dyn cm}^{-1}$ .

The general principles for purification procedures and the preparation of mixtures are those reviewed for the fluorides, chlorides, bromides and iodides [4-6]. Additional details are given for specific mixtures in section 5, this work.

TABLE II. Experimental techniques

Techniques	Aspects reviewed and reference
$\gamma$	Various possible methods and % application: This series, Vol. 2, Part 2 [2].
$\kappa, \rho, \eta, \gamma$	Descriptions of experimental assemblies: This series, Vol. 3 [3].
$\kappa, \rho, \eta, \gamma$	Practical aspects of studies with molten fluorides: This series, Vol. 4, Part 1 [4].
$\eta, \rho, \eta, \gamma$	Conductance: possible errors in measurements. Viscosity: comparison of oscillational and capillary techniques: This series, Vol. 4, Part 2 [5].
$\kappa$	Calibration techniques in molten salts conductivity measurements: This series, Vol. 4, Part 3 [6].

TABLE III. Percent application of techniques - mixed halide melts

Specific conductance	
Method	Percent application
Classical ac	95%
Other	5%
Density	
Archimedean	66%
Pycnometric, dilatometric	17%
Bubble pressure	11%
Flotation	6%
Viscosity	
Capillary	75%
Oscillational	25%
Surface tension	
Maximum bubble pressure	64%
Pin detachment	27%
Wilhelmy slide plate	9%

## 4. Treatment of Data

### 4.1. Statistical Analysis

The statistical analysis was performed on the computer facilities (IBM 360, PDP 15 and G.E. Mark II Time Sharing Unit) at Rensselaer Polytechnic Institute.

The density, specific conductance, viscosity and surface tension values were recalculated by a one-dimensional analysis, using the method of least squares to establish equations indicating the variations of the physical quantities with tem-

perature at the experimental composition. For density and surface tension results, where five or more experimental compositions and temperatures or temperature-dependent equations were reported, the values were recalculated by a two-dimensional analysis, using a stepwise multiple regression routine. In this way a physical property-temperature-composition matrix was developed. Tabulated values given in brackets indicate that the data base was minimal for statistical analysis, i.e., insufficient number of data points.

#### (a). One-Dimensional Analysis

The criterion for choosing the equation of best fit in the one-dimensional analysis is the standard error of estimate computed from the residuals and defined by

$$s = \sqrt{\frac{\sum_{i=1}^n (\gamma_e - \gamma_c)^2}{n - q}}$$

where  $\gamma_e$  = the experimental value at each temperature,  $\gamma_c$  = the value calculated from the least squares equation at the same temperature as  $\gamma_e$ ,  $n$  = the number of experimental data points, and  $q$  = the number of coefficients in the least squares equation (2 for linear, 3 for quadratic).

#### (b). Two-Dimensional Analysis

#### Computer Programs Used

Programs from the IBM Scientific Subroutine Package<sup>4</sup> were used with the IBM 360/65 computer facility at Rensselaer. The routines consist of STPRG, CORRE, LOC, and MSTR, the latter two being storage routines which have no effect on the accuracy of the results. In addition the subroutine STOUT is used to print the results of each regression step and the subroutine MATRIX is used for printing a matrix of the final equation.

#### Statistical Procedure

The abbreviated Doolittle method<sup>5</sup> was used to select the variables entering the regression and for calculation of coefficients. The independent variable included in each step of the analysis was selected by computing the reduction of sums of squares of each variable. The variable causing the largest reduction was added to the equation and deleted from the table of sums of squares. The coefficients, intercept and statistical parameters for the new equation were computed and printed. This procedure was repeated until the maximum proportion of sums of squares to the total reduced was less than a limit set by the programmer. The independent vari-

<sup>4</sup>System 360 Scientific Subroutine Package Programmers Manual; IBM H20-0205-3, 1969.

<sup>5</sup>C. A. Bennet and N. L. Franklin, *Statistical Analysis in Chemistry and the Chemical Industry* (John Wiley and Sons, 1954).

ables used in the initial selection were chosen from a generalized procedure, which generated 30 combinations of the input variables using powers, reciprocals, logarithmic and exponential quantities. It was found that the procedure consistently selected the combination  $(T + C)^3$  so that the working program used nine independent variables. After the final equation was produced, it was transferred to the MATRIX routine, which calculates values at rounded compositions and temperatures within specified boundary conditions. In the presentation of the matrix, due cognizance is taken of the experimental range of the investigation and of the phase relationships for the system so that values are always "interpolated" rather than "extrapolated". The final step in the procedure involves the residual analysis, where the deviations of the original values from those computed from the "best" equations are given.

*Statistical Parameters*

For each step in the regression analysis a summary of significant statistical parameters is given. First the sums of squares reduced ( $S_i$ ), the proportion of  $S_i/D$ , where  $D$  is defined below, given by  $P$ , the cumulative  $S_i$  given by  $S_{cum}$  and the cumulative proportion given by  $(P_{cum})$  are listed. These quantities give an indication of the effect of each variable in the final equation. The programmers limit on  $P$  was always in the range  $0.0001 \leq P \leq 0.001$ .

*Standard Error of Estimate*

The standard error in the estimated  $y$  values adjusted for degrees of freedom is given by:

$$s.e. = \sqrt{\frac{D - S_{cum}}{n - q - 1}}$$

where

$$D = \sum_{j=1}^n (y_j - \bar{y})^2$$

$y_j$  = experimental values

$\bar{y}$  = average of all experimental values

$q$  = the number of independent variables in the equations

As a general guide, about 68% of the results lie within the standard error of estimate, 95% within twice this value and approximately 99 percent within three times the value.<sup>6</sup> The standard error of estimate has been reported as a percent in this study. Where this information was reported in the literature as standard deviation, the preceding approach was not possible and we refer to the published error estimates of the original authors.

<sup>6</sup>I. D. Sterling and S. V. Pollack, Introduction to Statistical Data Processing (Prentice-Hall, 1968)

*F Value for Analysis of Variance*

This value is used to determine if a particular model is acceptable<sup>7</sup>. Tables of  $F$  values indicate that values greater than 2.0 are acceptable for the routine used here. In all cases values of  $F$  were greater than 500 and in most cases, greater than 1000. The  $F$  value is defined as:

$$F = \frac{S_{cum}/q}{(D - S_{cum})/(n - q - 1)}$$

where  $S_{cum}$ ,  $q$ ,  $D$ , and  $n$  were defined earlier.

**4.2. Value Judgements**

The recommendations advanced in this work are based on three criteria: (a) type and quantity of experimental data, (b) experimental method used, and (c) an error analysis of the reported results. The principles followed in selecting the most reliable data were as follows:

(a) Studies reporting either numerical data, results derived from statistically generated equations or data in the form of temperature-dependent equations were preferred over graphical results, except in those cases where the graphical results were based on a more complete investigation (i.e., wider composition or temperature range).

(b) The experimental aspects were examined, and the preparation, purification, stability and analyses of the single salts and binary melts were critically assessed. The reliability of the measuring technique (determined from standard "calibration" checks) was an important further consideration.

(c) The statistical parameters and percent departures as discussed in sections 4.1 and 4.3, respectively, were considered. For systems where investigations had similar quantity and quality of data, the results with superior statistical parameters were selected.

For some systems more than one reference was used to generate the recommendations. This was done to extend the recommended values to the widest possible range of composition and temperature.

**4.3. Physical Property Tables**

Four types of tables are used to present information relative to the physical properties.

(a) Number of investigations. In such tables, the published studies are analyzed with respect to:

- the investigations critically re-examined
- composition and temperature ranges

<sup>7</sup>H. Smith and N. R. Draper, Applied Regression Analysis (John Wiley and Sons, 1968)

- a summary of experimental details such as cell material and calibration method
- the minimum and maximum percent departures of the data with respect to NSRDS recommendations [1,2,4, 5,6, this volume].

The notation (g) indicates the data were presented graphically. Otherwise it is to be assumed that the data were reported in numerical or equation form. Footnotes to these tables call attention to information of unusual importance (technique, experimental uncertainty, etc.). A recommended reference is always indicated by a bold-face reference number. In situations where the composition-temperature-physical property data base is based on more than one investigation, all references used to develop the value judgments are listed in bold-face.

(b) Numerical values. Each table of values either contains the equation from which the values were calculated with the statistical parameters associated with it, or it has a footnote stating how the values were obtained. Where the experimental data were published in graphical form only, the numerical values were derived by interpolation.

(c) Percent departure. The percent departure has been used to compare the results of different investigations with either previous or current recommendations and has been considered when evaluating a study for possible recommendation.

The percent departure is given by

$$\text{Percent departure} = \frac{(\text{"compared value"} - \text{"recommended value"}) \cdot 100}{\text{"recommended value"}}$$

The recommended values are those in NSRDS-NBS 15 [1], NSRDS-NBS 28 [2], references [4, 5 or 6] or given in the present work. Only the maximum and minimum departures of the data from the NSRDS reference data base are reported. Percent departures are not given for data interpolated from graphical presentations.

(d) Summary tables. In section 6, a series of summarizing tables are developed to give information on the total number of investigations, the studies selected for the best-value recommendations, and related aspects of the work.

#### 4.4. Phase Diagrams

Phase, diagrams, where available, are included with the systems. It should be understood that these are not advanced as critically evaluated recommendations. The liquidus curves are used as boundary conditions in generating the matrix of recommended values in the two-dimensional analysis so that extrapolation into the solid state cannot occur. The literature reference for a phase diagram is given with the diagram.

## 5. Mixed Halide Systems

### 5.1. Fluoride-Chloride Systems

#### BaF<sub>2</sub>-BaCl<sub>2</sub>

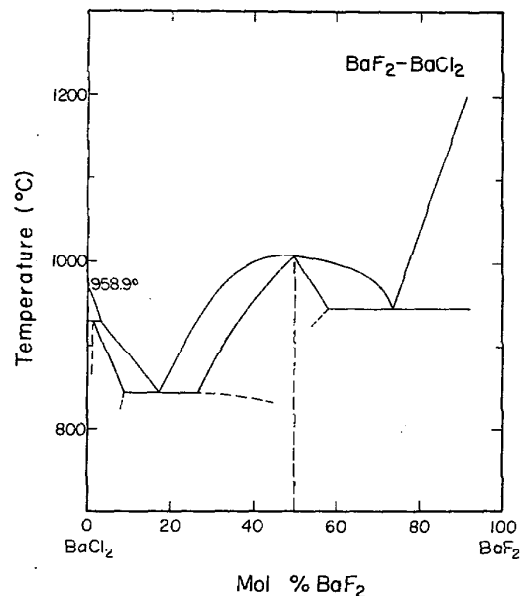


FIGURE 1. Temperature-composition phase diagram for BaF<sub>2</sub>-BaCl<sub>2</sub>. W. Plato, *Z. Phys. Chem.*, 58, 360 (1907).

#### Melt Preparation and Purification

Kuvakin and Klyakin [68] purified barium fluoride by roasting the commercial product with a mixture of ammonium fluoride and barium chloride. Similarly, barium chloride was treated with ammonium chloride to volatilize any impurities. The salts were fused before use.

Bukhalova and Yagub'yan [40] used recrystallized C. P. chemicals. Fluoride salts were prepared by dissolving the carbonates in hydrofluoric acid.

TABLE 1. Electrical conductance studies: BaF<sub>2</sub>-BaCl<sub>2</sub>

Investigations critically re-examined			
Ref.	BaCl <sub>2</sub> mol %	Temp. range (T)	Comments
68	50-100	1273-1373	Cell material: Pt vessel; Pt electrodes; frequency: 1000 Hz; calibration: molten NaCl, KCl and NaF.
Deviations from previous NSRDS recommendations [1, p. 7]			
Ref.	BaCl <sub>2</sub> mol %	Min. departure	Max. departure
68	100	-13.19% (1355 K)	-18.17% (1275 K)

TABLE 2. BaF<sub>2</sub>-BaCl<sub>2</sub>: Specific conductance (ohm<sup>-1</sup> cm<sup>-1</sup>)

T	Mol percent BaCl <sub>2</sub>				
	50.0	62.5	75.0	87.5	100
1275	1.457	1.106	1.035	1.268	1.784
1280	1.476	1.123	1.051	1.287	1.806
1285	1.495	1.139	1.067	1.305	1.829
1290	1.515	1.155	1.082	1.324	1.851
1300	1.553	1.188	1.113	1.361	1.892
1305	1.572	1.204	1.129	1.380	1.917
1310	1.591	1.220	1.145	1.398	1.940
1315	1.611	1.237	1.160	1.417	1.962
1320	1.630	1.253	1.176	1.436	1.984
1325	1.649	1.269	1.192	1.454	2.007
1330	1.669	1.285	1.207	1.473	2.029
1335	1.688	1.302	1.223	1.491	2.057
1340	1.707	1.318	1.254	1.529	2.095
1350	1.745	1.351	1.270	1.547	2.118
1355	1.765	1.367	1.285	1.566	2.140
1360	1.784	1.383	1.301	1.585	2.162
1365	1.803	1.399	1.317	1.603	2.185
1370	1.823	1.416	1.332	1.622	2.207

Temperature-dependent equations  
 $\kappa = a + bT$

Mol % BaCl <sub>2</sub>	-a	b · 10 <sup>3</sup>	Standard deviation
50	3.452	3.850	0.017
62.5	3.045	3.256	0.006
75	2.949	3.125	0.008
87.5	3.484	3.727	0.009
100	3.891	4.451	0.008

These values are based on the work of Kuvakin and Klyakin (classical ac technique) [68]. The data were reported in equation form. The standard deviations reported by the authors are given.

TABLE 3. Density studies: BaF<sub>2</sub>-BaCl<sub>2</sub>

Investigations critically re-examined			
Ref.	BaCl <sub>2</sub> mol %	Temp. range (T)	Comments
40	0-100 (g)	1573	Platinum sphere; calibration: volume of sphere determined using substances of known density.

TABLE 4. BaF<sub>2</sub>-BaCl<sub>2</sub>: Density (g cm<sup>-3</sup>)

Mol % BaF <sub>2</sub>	1573 K
0	2.94
10	2.98
20	3.03
30	3.12
40	3.22
50	3.34
60	3.46
70	3.61
80	3.74
90	3.86
100	3.94

These values have been interpolated to three significant figures from the graphical presentation of Bukhalova and Yagub'yan (Archimedean method) [40].

BaF<sub>2</sub>-KCl

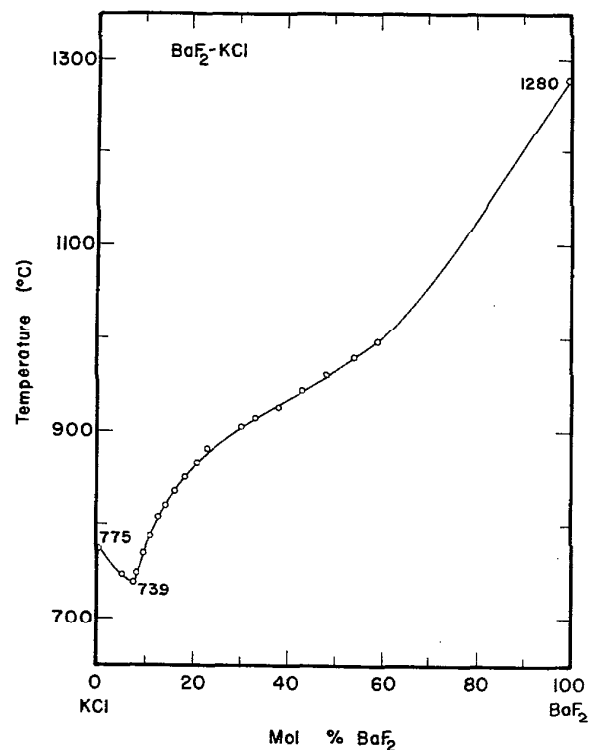


FIGURE 2. Temperature-composition phase diagram for BaF<sub>2</sub>-KCl.

E. I. Banashek and A. G. Bergman, Dokl. Akad. Nauk SSSR, 57, 905 (1947).

Melt Preparation and Purification

Bukhalova and Yagub'yan [31] used C. P. potassium chloride, recrystallized twice before use. Barium fluoride was prepared by dissolving the chemically-pure carbonate in hydrofluoric acid.

TABLE 5. Density studies: BaF<sub>2</sub>-KCl

Investigations critically re-examined			
Ref.	KCl mol %	Temp. range (T)	Comments
31	0-100 (g)	1573	Platinum sphere; calibration: volume of sphere determined using substances of known density.

TABLE 6. BaF<sub>2</sub>-KCl: Density (g cm<sup>-3</sup>)

Mol % BaF <sub>2</sub>	1573 K
0	1.20
10	1.50
20	1.80
30	2.06
40	2.34
50	2.62
60	2.92
70	3.14
80	3.40
90	3.68
100	3.96

These values have been interpolated to three significant figures from the graphical presentation of Bukhalova and Yagub'yan (Archimedean method) [31].

## CsF-CsCl

## Melt Preparation and Purification

References [85] and [65] (Smirnov et al.) give no information on melt preparation and purification. For a description of Smirnov's method of purifying LiCl, refer [5], p. 1005. See also KF-KCl. In a recent publication [94], Smirnov describes the preparation of alkali halide melts as follows: The salts were recrystallized and dried for 24 h during which time the temperature was raised gradually up to melting. Because it hydrolyzes relatively readily, LiCl was dehydrated under vacuum during 6 days, the temperature being increased very slowly to avoid caking of the salt. When it was molten, dry HCl was bubbled through the melt for approximately 6 h. All salt mixtures with LiCl were prepared in a similar way. Contact with quartz was avoided to prevent contamination of the melts by oxide.

TABLE 7. Electrical conductance studies: CsF-CsCl

Investigations critically re-examined			
Ref.	CsCl mol %	Temp. range (T)	Comments
85	0-100	923-1183	Pt electrodes; freq. range: 50,000 Hz.

Deviations from previous NSRDS recommendations [1, pp. 3,6]

Ref.	CsCl mol %	Min. departure	Max. departure
85	100	0.06% (960 K)	-5.49% (1070 K)
85	0	-1.58% (1010 K)	-4.69% (1125 K)



TABLE 8. CsF-CsCl: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

T	Mol percent CsCl								
	100	88	75	63	50	37	25	12	0
930	1.160								
940	1.184								
950	1.208								
960	1.232	1.285	1.374		1.564				
970	1.255	1.307	1.396		1.589		1.885		
980	1.279	1.329	1.417	1.504	1.613	1.763	1.915	2.134	
990	1.301	1.351	1.439	1.526	1.637	1.790	1.945	2.163	2.456
1000	1.324	1.373	1.461	1.548	1.661	1.816	1.975	2.191	2.488
1010	1.346	1.395	1.483	1.570	1.684	1.841	2.004	2.219	2.520
1020	1.368	1.416	1.505	1.592	1.707	1.867	2.033	2.247	2.551
1030	1.390	1.438	1.527	1.613	1.730	1.891	2.062	2.274	2.583
1040	1.412	1.459	1.548	1.635	1.753	1.915	2.090	2.301	2.614
1050	1.433	1.480	1.570	1.657	1.775	1.939	2.118	2.328	2.645
1060	1.454	1.501	1.592	1.678	1.797	1.963	2.145	2.355	2.677
1070	1.475	1.522	1.614	1.699	1.819	1.985	2.172	2.381	2.708
1080		1.543	1.636	1.721	1.840	2.008	2.199	2.407	2.739
1090		1.564	1.658	1.742	1.861	2.030	2.225	2.433	2.770
1100		1.585	1.680	1.763	1.882	2.051	2.251	2.459	2.801
1110		1.605	1.703	1.785	1.902	2.072	2.276	2.484	2.832
1120		1.626	1.725	1.806	1.922	2.093	2.301	2.509	2.863
1130		1.646	1.747	1.827	1.942	2.113	2.326	2.534	2.893
1140		1.666	1.769	1.848	1.961	2.132	2.350	2.559	2.924
1150		1.687	1.791	1.869	1.980	2.152	2.374	2.583	2.955
1160		1.707	1.813		1.999	2.170	2.398	2.607	2.985
1170		1.726	1.836		2.018	2.189	2.421	2.631	3.016
1180			1.858			2.207			3.046
1190			1.880						
1200			1.903						
1210			1.925						
1220			1.948						
1230			1.970						
1240			1.993						

Temperature-dependent equations

$$\kappa = a + bT + cT^2$$

Mol % CsCl	a	$b \cdot 10^3$	$-c \cdot 10^6$	Standard deviation
0	1.055	3.918	0.375	0.006
12	1.853	5.286	1.242	0.008
25	2.897	6.794	1.922	0.002
37	3.037	7.127	2.274	0.005
50	2.228	5.419	1.530	0.001
63	0.951	2.811	0.312	0.003
75	0.567	1.877	-0.151	0.004
88	1.330	3.236	0.533	0.004
100	2.271	4.943	1.348	0.002

These values are based on the work of Smirnov, Shumov, Stepanov, Khokhlov and Noskevich (classical ac technique) [85].

TABLE 9. Density studies: CsF-CsCl

Investigations critically re-examined			
Ref.	CsCl mol %	Temp. range (T)	Comments
85	0-100	923-1073	Cell material: Pt sphere; calibration: molten KNO <sub>3</sub> .

Deviations from previous NSRDS recommendations [1, pp. 3,5]

Ref.	CsCl mol %	Min. departure	Max. departure
85	100	0.40% (940 K)	0.53% (1070 K)
85	0	-0.28% (1070 K)	-0.39% (1010 K)

TABLE 10. CsF-CsCl: Density (g cm<sup>-3</sup>)

T	Mol percent CsCl								
	100	88	75	63	50	37	25	12	0
930	2.789	2.857	2.934	3.035	3.141	3.259	3.404	3.543	3.688
940	2.779	2.846	2.924	3.023	3.129	3.247	3.391	3.529	3.676
950	2.768	2.835	2.913	3.011	3.117	3.235	3.378	3.515	3.663
960	2.758	2.825	2.902	2.999	3.105	3.223	3.364	3.502	3.651
970	2.747	2.813	2.891	2.988	3.093	3.211	3.351	3.489	3.639
980	2.737	2.803	2.881	2.976	3.081	3.199	3.338	3.475	3.627
1000	2.716	2.792	2.870	2.964	3.070	3.187	3.324	3.462	3.615
1010	2.705	2.770	2.848	2.941	3.046	3.163	3.298	3.435	3.591
1020	2.695	2.759	2.837	2.929	3.034	3.151	3.285	3.422	3.579
1030	2.684	2.748	2.827	2.917	3.022	3.139	3.271	3.400	3.567
1040	2.673	2.737	2.816	2.905	3.011	3.126	3.258	3.395	3.555
1050	2.663	2.726	2.805	2.893	3.000	3.114	3.245	3.381	3.542
1060	2.652	2.715	2.794	2.882	2.987	3.102	3.231	3.368	3.530
1070	2.642	2.704	2.784	2.870	2.975	3.090	3.218	3.354	3.518

Temperature-dependent equations

$$\rho = a - bT$$

Mol % CsCl	a	b · 10 <sup>3</sup>	Standard deviation
0	4.8135	1.2105	0.0004
12	4.7942	1.3456	0.0006
25	4.6394	1.3283	0.0013
37	4.3801	1.2054	0.0008
50	4.2382	1.1803	0.0009
63	4.1302	1.1778	0.0009
75	3.9361	1.0770	0.0007
88	3.8766	1.0959	0.0008
100	3.7693	1.0536	0.0004

These values are based on the work of Smirnov, Shumov, Stepanov, Khokhlov, and Noskevich (Archimedean method) [85]. The following equation, with concentration, C, in mole percent CsCl and temperature in K, has been derived from the preceding data:  $\rho = \epsilon + bT + cC^2 + dTC + eTC^2 + fCT^2$ , where  $a = 4.90268$ ,  $b \cdot 10^3 = -1.30079$ ,  $c \cdot 10^5 = 2.54535$ ,  $d \cdot 10^5 = -2.71649$ ,  $e \cdot 10^8 = 1.50924$ ,  $f \cdot 10^8 = 1.42221$ , with a maximum departure of 0.33% at 923 K and 75 mol % CsCl, and a standard error of estimate of 0.002. This equation may be used to calculate the density of CsF-CsCl melts at any given composition in the temperature range 923-1073 K.

TABLE 11. Viscosity studies: CsF-CsCl

Investigations critically re-examined		
Ref.	CsCl mol %	Temp. range
65	0-100	See footnote a.
Deviation from previous NSRDS recommendations [Vol. 4, Pt. 2]		
Ref.	CsCl mol %	Departure
65	100	-2.82% (1070 K)

<sup>a</sup>The temperature range was not given. The isotherm at 1070 K (molar viscosity vs. composition) was reported and the values in the following table were calculated from this set of data.

TABLE 12. CsF-CsCl: Viscosity (cp)

Mol % CsCl	1070 K
0	1.30 <sub>4</sub>
12	1.17 <sub>3</sub>
25	1.10 <sub>8</sub>
37	1.06 <sub>8</sub>
50	1.07 <sub>9</sub>
63	1.07 <sub>3</sub>
75	1.06 <sub>4</sub>
88	1.06 <sub>1</sub>
100	1.03 <sub>4</sub>

These values are based on the work of Smirnov, Khokhlov and Antonov (oscillating sphere method) [65] and the density data of Smirnov, Shumov, and Khokhlov [83]. The data were reported in equation form and no estimate of error was given.

 TABLE 13. CsF-CsCl: Molar viscosity ( $\text{erg s mol}^{-1}$ )<sup>a</sup>

Temperature-dependent equations $\log \eta_M = A + B/T$		
Mol % CsCl	-A	B
0	1.6660	1516
12	1.2178	1015
25	1.2219	1019
37	1.2308	1036
50	1.1422	970
63	1.1259	974
75	1.1731	1039
88	1.1666	1050
100	1.1743	1065

Equations as reported by Smirnov, Khokhlov and Antonov [65] (see footnote, table 11); of limited value since temperature limits of applicability and standard deviation were not reported.

<sup>a</sup>Molar viscosity is defined by  $\eta(M\rho^{-1})$ , where  $M = X_1M_1 + X_2M_2$  and  $\rho$ ,  $X_1$ ,  $X_2$  are the density and mol fraction composition of the molten mixture, with the units of  $\eta$  in poise.

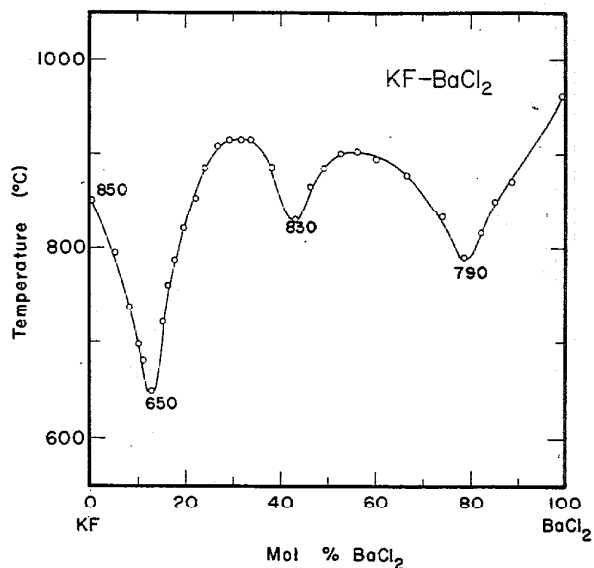
 KF-BaCl<sub>2</sub>


FIGURE 3. Temperature-composition phase diagram for KF-BaCl<sub>2</sub>. E. I. Banashek and A. G. Bergman, Dokl. Akad. Nauk SSSR, 57, 905 (1947).

## Melt Preparation and Purification

Bukhalova and Yagub'yan [31] purified chemically pure barium chloride by recrystallizing twice from aqueous solution. Potassium fluoride was prepared by reacting chemically pure potassium carbonate with hydrofluoric acid.

 TABLE 14. Density studies: KF-BaCl<sub>2</sub>

Investigations critically re-examined			
Ref.	BaCl <sub>2</sub> mol %	Temp. range (T)	Comments
31	0-100 (g)	1573	Platinum sphere; calibration: volume of sphere determined using substances of known density.

 TABLE 15. KF-BaCl<sub>2</sub>: Density ( $\text{g cm}^{-3}$ )

Mol % BaCl <sub>2</sub>	1573
0	1.60
10	1.74
20	1.90
30	2.06
40	2.21
50	2.35
60	2.50
70	2.61
80	2.72
90	2.84
100	2.93

These values have been interpolated to three significant figures from the graphical presentation of Bukhalova and Yagub'yan (Archimedean method) [31].

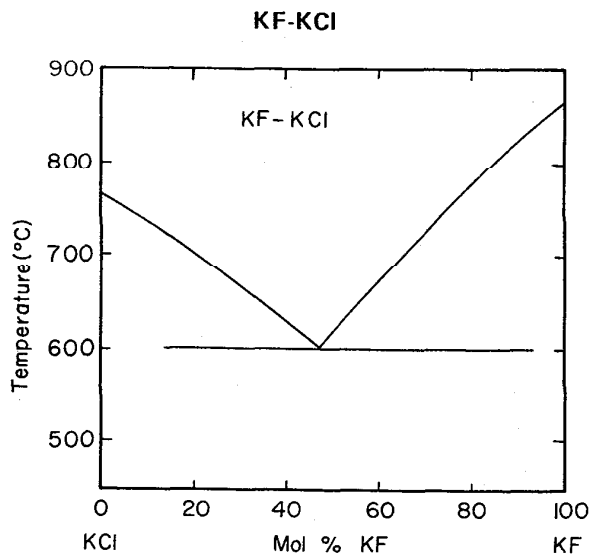


FIGURE 4. Temperature-composition phase diagram for KF-KCl.  
W. Plato, *Z. Phys. Chem.*, 58, 364 (1907).

#### Melt Preparation and Purification

Holm and Berge [60, 88] used reagent-grade KF and KCl dried at 400 – 500 °C under moderate vacuum (0.1 – 0.01

torr) and then melted in a platinum crucible in an atmosphere of purified nitrogen.

Narushkin, Patrov, and Chebotarev [87] used chemically pure KF and KCl dried to constant weight at 100 – 150 °C. The salts were then cooled in a desiccator and weighed in sintered corundum containers in an argon atmosphere.

Smirnov et al. [84] used high purity potassium halides. Anhydrous KF was obtained by dehydrating  $\text{KF} \cdot 2\text{H}_2\text{O}$ .

TABLE 16. Electrical conductance studies: KF-KCl

Investigations critically re-examined			
Ref.	KCl mol %	Temp. range (T)	Comments
84	0-100	993-1293	Pt electrodes; freq. range 50,000 Hz.
Deviations from previous NSRDS recommendations [1, pp. 3,5]			
Ref.	KCl mol %	Min. departure	Max. departure
84	100	-0.11% (1065 K)	-0.11% (1195 K)
84	0	-7.44% (1155 K)	-7.64% (1220 K)

TABLE 17. KF-KCl: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

T	Mol percent KCl							
	100	88	75	63	50	37	12	0
1000			2.065	2.155				
1010			2.099	2.187				
1020			2.133	2.218				
1030		2.067	2.166	2.249	2.340	2.470		
1040		2.094	2.199	2.280	2.373	2.502		
1050		2.121	2.231	2.309	2.405	2.534		
1060	2.200	2.147	2.262	2.339	2.436	2.565		
1070	2.227	2.173	2.293	2.367	2.467	2.596		
1080	2.252	2.198	2.323	2.395	2.497	2.626		
1090	2.277	2.223	2.352	2.395	2.497	2.626		
1100	2.302	2.247	2.380	2.450	2.555	2.685		
1110	2.326	2.270	2.408	2.476	2.583	2.713	3.013	
1120	2.349	2.293	2.436	2.502	2.611	2.741	3.041	
1130	2.372	2.316	2.462	2.527	2.638	2.768	3.068	
1140	2.394	2.338	2.489	2.552	2.664	2.795	3.095	
1150	2.415	2.359	2.514	2.576	2.690	2.821	3.122	
1160	2.436	2.381	2.539	2.600	2.715	2.847	3.149	3.373
1170	2.457	2.401	2.563	2.623	2.739	2.872	3.176	3.400
1180	2.476	2.421	2.586	2.645	2.763	2.897	3.203	3.426
1190	2.495	2.440	2.609	2.667	2.786	2.921	3.229	3.453
1200	2.514	2.459	2.631	2.689	2.808	2.945	3.255	3.481
1210	2.532	2.478	2.653	2.709	2.830	2.968	3.282	3.509
1220	2.549	2.496	2.673	2.730	2.851	2.990	3.308	3.537
1230	2.566	2.513	2.694	2.749	2.872	3.012	3.334	3.565
1240	2.582	2.530	2.713	2.767	2.892	3.033	3.360	3.594
1250	2.597	2.546	2.732			3.054	3.386	3.623
1260	2.612	2.562				3.075	3.411	3.653
1270	2.626	2.577				3.094	3.437	3.682
1280							3.462	
1290							3.488	

PROPERTIES OF MIXED HALIDE MELTS

TABLE 17. KF-KCl: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )—Continued

Temperature-dependent equations $\kappa = a + bT + cT^2$				
Mol % KCl	$-a$	$b \cdot 10^3$	$-c \cdot 10^6$	Standard deviation
0	-2.660	-1.392	-1.730	0.012
12	0.794	4.115	0.617	0.007
37	3.775	8.871	2.726	0.004
50	4.455	9.894	3.201	0.006
63	3.864	8.811	2.792	0.005
75	4.648	9.948	3.235	0.003
88	3.525	8.107	2.600	0.006
100	3.989	9.019	3.000	

These values are based on the work of Smirnov, Shumov, Khokhlov, Stepanov, Noskevich and Antonenko (classical ac technique) [84].

TABLE 10. Density studies. KF-KCl

Investigations critically re-examined			
Ref.	KCl mol %	Temp. range ( $T$ )	Comments
84	0-100	993-1253	Pt ball; calibration: molten $\text{KNO}_3$ .
60,88	50	1077.4, 1136.4, 1190.0	Pt-10% Rh sinker; calibration: water.
Deviations from previous NSRDS recommendations [1, pp. 3,5 and this volume]			
Ref.	KCl mol %	Min. departure	Max. departure
84	100	0.35% (1140 K)	0.38% (1020 K)
60,88	50	-0.78% (1077.4 K)	-0.92% (1136.4 K)
84	0	0.36% (1150 K)	1.91% (1250 K)

TABLE 19. KF-KCl: Density ( $\text{g cm}^{-3}$ )

$T$	Mol percent KCl							
	100	88	75	63	50	37	12	0
1000						1.803		
1010			1.617			1.797		
1020		1.576	1.611			1.790		
1030		1.570	1.605			1.784		
1040		1.564	1.599			1.778		
1050		1.558	1.593			1.772		
1060	1.516	1.552	1.587	1.626	1.675	1.766		
1070	1.510	1.546	1.581	1.619	1.669	1.760		
1080	1.505	1.540	1.575	1.613	1.662	1.754		
1090	1.499	1.534	1.569	1.607	1.656	1.748	1.856	
1100	1.493	1.529	1.563	1.601	1.650	1.742	1.850	
1120	1.481	1.517	1.551	1.589	1.638	1.729	1.836	
1130	1.476	1.511	1.545	1.583	1.631	1.723	1.830	
1140	1.470	1.505	1.539	1.577	1.625	1.717	1.823	
1150	1.464	1.499	1.533	1.571	1.619	1.711	1.817	1.904
1160	1.458	1.493	1.527	1.565	1.613		1.810	1.898
1170	1.453	1.487	1.521	1.559	1.607		1.803	1.891
1180	1.447		1.515	1.552	1.601		1.797	1.884
1190	1.441		1.509	1.546	1.595		1.790	1.877
1200			1.503	1.540	1.588		1.783	1.871
1210				1.534	1.582		1.777	1.864
1220				1.528	1.576		1.770	1.857
1230				1.522	1.570		1.763	1.850
1240				1.516	1.564			1.844
1250				1.510	1.557			1.837

Temperature-dependent equations

$$\rho = a - bT$$

Mol % KCl	$a$	$b \cdot 10^3$	Standard deviation
0	2.6806	0.6750	0.0002
12	2.5800	0.6639	0.0005
37	2.4136	0.6109	0.0006
50	2.3296	0.6177	0.0003
63	2.2722	0.6100	0.0004
75	2.2187	0.5962	0.0004
88	2.1830	0.5950	0.0003
100	2.1300	0.5790	0.0010

These values are based on the work of Smirnov, Shumov, Stepanov, Khokhlov and Noskevich (Archimedean method) [84].

TABLE 20. Surface tension studies: KF-KCl

Investigations critically re-examined			
Ref.	KCl mol %	Temp. range ( $T$ )	Comments
60	50	1073	Pt-10% Rh sinker; calibration: water.
87	10-90	1173	Calibration: molten NaCl, KCl, NaF, KF.

TABLE 21. KF-KCl: Surface tension ( $\text{dyn cm}^{-1}$ )

Mol % KCl	1173 K
10	92.3
20	96.3
30	96.3
40	99.6
50	103.8
60	106.0
70	106.9
80	110.1
90	114.7

The values in this table are those obtained experimentally by Narushkin, Patrov and Chebotarev (modified maximum bubble pressure method) [87].

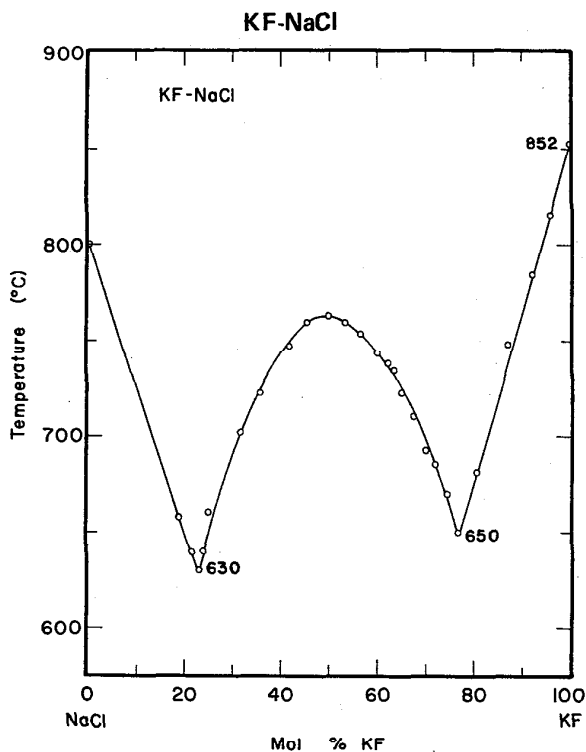


FIGURE 5. Temperature-composition phase diagram for KF-NaCl. V. D. Polykov and S. I. Berul, *Izv. Sek. Fiz.-Khim., Nal. Inst. Ob. Neorg. Khim., Akad. Nauk SSSR*, 22, 170 (1953).

#### Melt Preparation and Purification

Ryschkewitsch [9] used chemically pure KF and NaCl, and carried out the measurements under dry nitrogen.

TABLE 22. Electrical conductance studies: KF-NaCl

Investigations critically re-examined			
Ref.	NaCl mol %	Temp. range (T)	Comments
9	0,33,66, 100 <sup>a</sup>	983-1273	Cell material: quartz cell or Pt crucible; Pt electrodes; freq. range: $\approx 6000$ Hz; calibration: H <sub>2</sub> SO <sub>4</sub> solutions, saturated NaCl solution, molten KNO <sub>3</sub> .

<sup>a</sup>Ryschkewitsch reported the specific conductance of single salt melts graphically. The temperature measurements were accurate to within 1°C.

TABLE 23. KF-NaCl: Specific conductance (ohm<sup>-1</sup> cm<sup>-1</sup>)

T	Mol percent NaCl		
	66.6	50	33.3
990	2.32		2.57
1000	2.41	2.70	2.69
1010	2.51	2.78	2.81
1020	2.59	2.86	2.93
1030	2.68	2.94	3.04
1040	2.77	3.02	3.14
1050	2.86	3.10	3.24
1060	2.94	3.18	3.34
1070	3.03	3.26	3.43
1080	3.11	3.33	3.52
1090	3.19	3.40	3.60
1100	3.27	3.48	3.60
1110	3.35	3.55	3.76
1120	3.43	3.62	3.83
1130	3.51	3.69	3.89
1140	3.59	3.76	3.95
1150	3.66	3.83	4.01
1160	3.74	3.89	4.06
1170	3.81	3.96	4.11
1180	3.88	4.02	4.15
1190	3.95	4.09	4.19
1200	4.02	4.15	4.23
1210	4.09	4.21	
1220	4.16	4.27	
1230	4.23	4.33	
1240	4.29		
1250	4.36		
1260	4.42		
1270	4.49		

#### Temperature-dependent equations

$$\kappa = a + bT + cT^2$$

NaCl mol %	a	b · 10 <sup>2</sup>	c · 10 <sup>6</sup>	Standard error of estimate
33.3	-31.6045	5.6488	-22.1904	4.33%
50	-11.3609	1.9723	- 5.6670	2.11%
66.6	-12.1839	2.0052	- 5.4536	2.32%

These values are based on the work of Ryschkewitsch (classical ac technique) [9].

TABLE 24. Density studies: KF-NaCl

Investigations critically re-examined		
Ref.	KF mol %	Temp. range (T)
43	0-70 (g)	1073

TABLE 25. KF-NaCl: Molar volume (cm<sup>3</sup>) and density (g cm<sup>-3</sup>)

Mol % KF	Molar volume (T = 1073 K)	Density (T = 1073 K)
0	37.7	1.55
10	37.5	1.56
20	37.0	1.58
30	36.4	1.60
40	35.7	1.63
50	34.9	1.67
60	34.3	1.70
70	33.5	1.74

These values are based on the work of Markov and Prisyazhnyii [43] (Archimedean method). The values were obtained by interpolation of the graphically-presented results (mole volume), and subsequent conversion of this data to densities in the conventional manner.

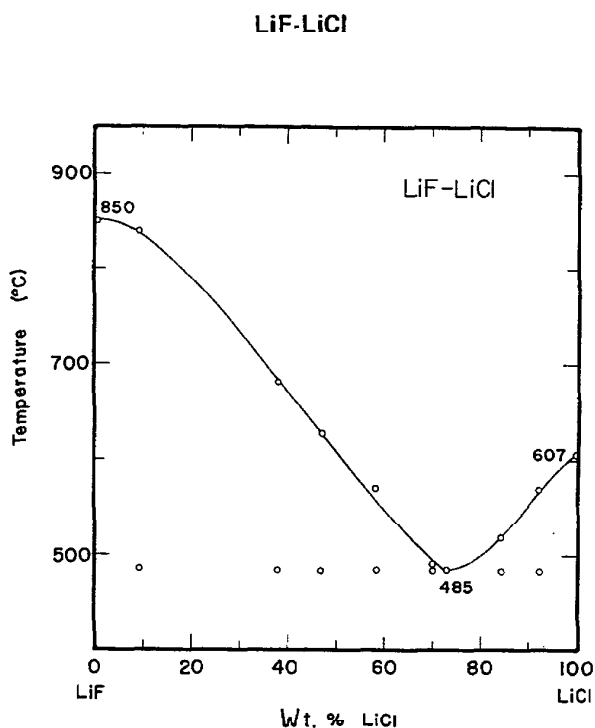


FIGURE 6. Temperature-composition phase diagram for LiF-LiCl.

A.A. Bochvar, *Tsvetn. Metall.* 1, 508 (1930); *Z. Anorg. Allg. Chem.* 210, 183 (1933).

## Melt Preparation and Purification

Danielyan and Belyaev [52] used salts prepared from chemically pure reagents dried at 150 °C for several hours.

Holm and Berge [60, 88] used reagent grade lithium fluoride and lithium chloride dried at 400-500 °C under moderate vacuum (0.1-0.01 torr) and then melted in a platinum crucible under an atmosphere of purified nitrogen.

References [79] and [82] (Smirnov et al.) contain no information on melt preparation. However, see CsF-CsCl.

TABLE 26. Electrical conductance studies: LiF-LiCl

Investigations critically re-examined			
Ref.	LiCl mol %	Temp. range (T)	Comments
52	60, 69.5, 80, 100 (g)	≈788-1033	Cell material: quartz capillary; Pt disc-shaped electrodes; freq. range: 2000-20,000 Hz; calibration: 0.1 M KCl.
82	0-100	933-1273	Pt electrodes; freq. range: 50,000 Hz.

Deviations from previous NSRDS recommendations [1, pp. 3,4]

Ref.	LiCl mol %	Min. departure	Max. departure
82	100	0.00% (970 K)	-0.15% (1055 K)
82	0	0.03% (1260 K)	-2.56% (1150 K)



PROPERTIES OF MIXED HALIDE MELTS

TABLE 27. LiF-LiCl: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

T	Mol percent LiCl								
	100	88	75	63	50	37	25	12	0
940	6.023	5.463	4.856	4.610	4.741	4.915	5.391	5.912	6.700
960	6.118	5.566	4.973	4.743	4.880	5.081	5.556	6.081	6.895
980	6.211	5.656	5.095	4.867	5.025	5.244	5.717	6.245	7.077
1000	6.299	5.749	5.205	4.994	5.161	5.402	5.875	6.403	7.254
1020	6.379	5.833	5.317	5.110	5.295	5.552	6.026	6.561	7.421
1040	6.464	5.915	5.419	5.229	5.427	5.709	6.175	6.706	7.590
1060	6.541	5.996	5.527	5.345	5.556	5.856	6.321	6.860	7.755
1080	6.613	6.072	5.626	5.452	5.679	6.000	6.461	7.005	7.917
1100	6.684	6.143	5.720	5.562	5.801	6.143	6.603	7.139	8.071
1120	6.749	6.213	5.816	5.665	5.917	6.282	6.738	7.283	8.218
1140	6.811	6.282	5.903	5.763	6.035	6.421	6.867	7.410	8.368
1160	6.875	6.342	5.992	5.864	6.147	6.547	6.999	7.539	8.510
1180	6.931	6.401	6.072	5.959	6.253	6.677	7.118	7.664	8.645
1200	6.981	6.455	6.155	6.048	6.357	6.805	7.241	7.788	8.784
1220	7.031	6.512	6.232	6.136	6.460	6.926	7.357	7.900	8.914
1240	7.076	6.561	6.304	6.222	6.557	7.045	7.471	8.021	9.042
1260	7.120	6.608	6.374	6.037	6.651	7.163	7.583	8.134	9.164

Temperature-dependent equation  
 $\kappa = a + bT + cT^2 + dT^3$

Mol % LiCl	-a	$b \cdot 10^2$	$-c \cdot 10^6$	$d \cdot 10^{10}$	Stand. error of est.
100	2.38328	1.30626	4.38178		0.022%
88	3.79487	1.53803	6.54756	7.08847	0.029%
75	4.53422	1.39024	4.16275		0.031%
63	5.09117	1.40770	3.99430		0.031%
50	4.45470	1.14329	0.812034	10.05267	0.024%
37	6.50401	1.59769	4.07234		0.029%
25	6.35426	1.67159	4.48874		0.023%
12	6.13153	1.72097	4.67529		0.041%
0	6.62282	1.90497	5.17567		0.025%

These values are based on the work of Smirnov, Khokhlov, Stepanov, and Shumov (classical ac technique) [82]. These authors reported equivalent conductivities in the form of semilogarithmic equations. The original data were converted to specific conductivities using the density equations reported in the same paper.

TABLE 28. Density studies: LiF-LiCl

Investigations critically re-examined			
Ref.	LiCl mol %	Temp. range (T)	Comments
60	50	982.2, 1014.2, 1085.2	Pt-10% Rh sinker; calibration: water.
82	0-100	933-1273	Pt sphere; calibration: molten $\text{KNO}_3$ .
Deviations from NSRDS recommendations [1, pp. 3, 4 and this volume]			
Ref.	LiCl mol %	Min. departure	Max. departure
82	100	-0.03% (930 K)	-0.14% (1050 K)
60	50	0.33% (1085.2 K)	0.76% (982.2 K)
82	0	0.01% (1210 K)	0.28% (1270 K)

TABLE 29. LiF-LiCl: Density ( $\text{g cm}^{-3}$ )

$T$	Mol percent LiCl								
	100	88	75	63	50	37	25	12	0
940	1.477	1.493	1.517	1.548	1.588	1.640	1.699	1.768	1.877
960	1.468	1.485	1.508	1.540	1.579	1.631	1.691	1.760	1.869
980	1.459	1.476	1.500	1.531	1.571	1.623	1.682	1.751	1.860
1000	1.450	1.467	1.491	1.522	1.562	1.614	1.673	1.743	1.852
1020	1.441	1.458	1.482	1.513	1.553	1.605	1.664	1.735	1.844
1040	1.432	1.449	1.473	1.504	1.544	1.597	1.655	1.726	1.835
1060	1.423	1.441	1.465	1.496	1.536	1.588	1.646	1.718	1.827
1080	1.414	1.432	1.456	1.487	1.527	1.579	1.637	1.710	1.819
1100	1.405	1.423	1.447	1.478	1.518	1.570	1.629	1.701	1.811
1120	1.396	1.414	1.439	1.469	1.509	1.562	1.620	1.693	1.802
1140	1.387	1.406	1.430	1.460	1.501	1.553	1.611	1.685	1.794
1160	1.379	1.397	1.421	1.452	1.492	1.544	1.602	1.676	1.786
1180	1.370	1.397	1.421	1.452	1.492	1.544	1.602	1.676	1.786
1200	1.361	1.379	1.421	1.452	1.492	1.544	1.602	1.676	1.786
1220	1.352	1.371	1.395	1.425	1.466	1.518	1.575	1.651	1.761
1240	1.343	1.362	1.386	1.416	1.457	1.509	1.567	1.643	1.753
1260	1.334	1.353	1.377	1.408	1.448	1.501	1.558	1.634	1.744

Temperature dependent equations

$$\rho = a - bT$$

Mol % LiCl	$a$	$b \cdot 10^3$	Standard deviation
0	2.266	0.414	0.002
12	2.160	0.417	0.003
25	2.116	0.443	0.003
37	2.050	0.436	0.003
50	2.000	0.438	0.002
63	1.962	0.440	0.004
75	1.928	0.437	0.004
88	1.905	0.438	0.004
100	1.896	0.446	0.005

These values are based on the work of Smirnov, Khokhlov, Stepanov and Shumov (modified maximum bubble pressure method) [82]. The following equation, with concentration,  $C$ , in mole percent LiCl and temperature in K, has been derived from the preceding data:  $\rho = a + bC + cT + dC^2 + eC^3 + fTC^2 + gCT^2$ , where  $a = 2.25621$ ,  $b \cdot 10^3 = -8.20475$ ,  $c \cdot 10^4 = -4.09235$ ,  $d \cdot 10^5 = 6.37250$ ,  $e \cdot 10^7 = -2.52846$ ,  $f \cdot 10^9 = 8.73570$ ,  $g \cdot 10^{10} = -5.11184$ , with a maximum departure of 0.54% at 933 K and 12.0 mol % LiCl, and a standard error of estimate of 0.004. This equation may be used to calculate the density of LiF-LiCl melts at any given composition in the temperature range 933-1273 K.

TABLE 30. Surface tension studies: LiF-LiCl

Investigations critically re-examined			
Ref.	LiCl mol %	Temp. range: (T)	Comments
88	50	1073	Pt-10% Rh sinker; calibration: water.
79	0-88	929-1240	Cell material: Mo crucible; calibration: molten NaCl.
Deviations from NSRDS recommendations [2, p. 55 and this volume]			
Ref.	LiCl mol %	Min. departure	Max. departure
88	50	-18.45% (1073 K)	
79	0	1.70% (1170 K)	1.76% (1240 K)

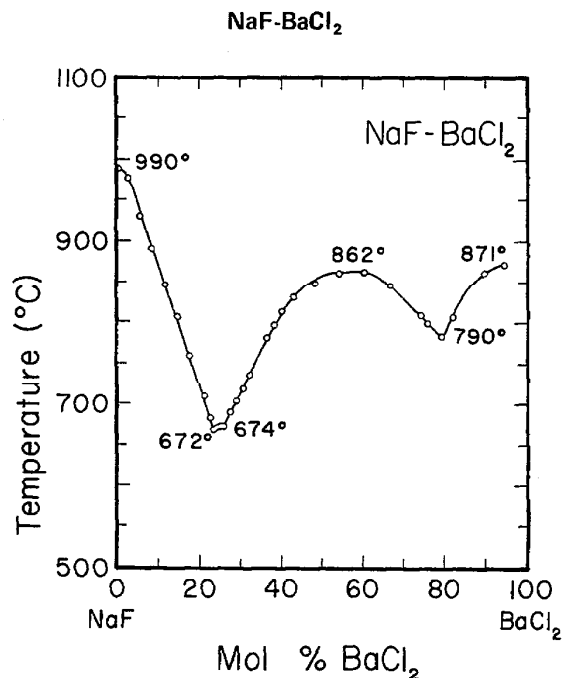
TABLE 31. LiF-LiCl: Surface tension (dyn cm<sup>-1</sup>)

T	Mol percent LiCl							
	88	75	63	50	37	25	12	0
930	144.9							
940	144.1							
950	143.2							
960	142.4	152.2						
970	141.5	151.3	162.1					
980	140.7	150.5	161.2					
990	139.8	149.7	160.3					
1000	139.0	148.8	159.4					
1010	138.1	147.9	158.5					
1020	137.3	147.1	157.6	171.3				
1030	136.5	147.1	157.6	171.3				
1040	135.6	145.4	155.8	169.4				
1050	134.8	144.5	154.9	168.5				
1060	133.9	143.7	154.0	167.6	184.0			
1070	133.1	142.8	153.1	165.8	183.0	200.8		
1080	132.3	142.0	152.1	164.9	182.1	199.8		
1090	131.4	141.1	151.2	164.0	181.2	198.9		
1100	130.6	140.3	150.3	163.1	180.3	197.9	219.4	241.7
1110	129.7	139.4	149.4	162.1	179.3	197.0	218.5	240.7
1120		138.6	148.5	161.2	178.4	196.0	217.5	239.8
1130		137.7	147.6	160.3	177.5	195.0	216.6	238.8
1140		136.9	146.7	159.4	176.6	194.1	215.6	237.8
1150			145.8	158.5	175.7	193.1	214.7	236.8
1160				157.6	174.7	192.2	213.7	235.8
1170					173.8	191.2	212.8	234.8
1180					172.9	190.3	211.8	233.9
1190					172.0	189.3	210.9	232.9
1200						188.3	209.9	231.9
1210							209.0	230.9
1220							208.0	229.9
1230								228.9
1240								227.9

Temperature-dependent equations  
 $\gamma = a + bT$

Mol % LiCl	a	-b
0	350.2	0.0986
12	323.8	0.0949
25	303.3	0.0958
37	281.7	0.0922
50	264.4	0.0913
63	250.0	0.0906
75	234.1	0.0853
88	223.2	0.0842

These values are based on the work of Smirnov and Stepanov (maximum bubble pressure method) [79]. The following equation, with concentration, C, in mole percent LiCl and temperature in K, has been derived from the preceding data:  $\gamma = a + bTC + cC^2 + dCT^2 + eTC^2 + fT^3$ , where  $a = 271.25732$ ,  $b \cdot 10^3 = -2.89297$ ,  $c \cdot 10^4 = -4.13850$ ,  $d \cdot 10^6 = 1.04392$ ,  $e \cdot 10^6 = 7.27278$ ,  $f \cdot 10^8 = -2.89297$ , with a maximum departure of 0.37% at 1109 K and 88 mol % LiCl, and a standard error of estimate of 0.317. This equation may be used to calculate the surface tension of LiF-LiCl melts at any given composition in the temperature range 929-1240 K.

FIGURE 7. Temperature-composition phase diagram for NaF-BaCl<sub>2</sub>.

E. I. Banashek and A. G. Bergman, Dokl. Akad. Nauk SSSR, 56, 485 (1947).

**Melt Preparation and Purification**

Taniuchi [47] used best quality commercial reagents dried at 110 °C and kept in a desiccator.

TABLE 32. Electrical conductance studies: NaF-BaCl<sub>2</sub>

Investigations critically re-examined			
Ref.	BaCl <sub>2</sub> mol %	Temp. range (T)	Comments
47	0-100 (g) <sup>a</sup>	1123, 1173, 1273	Cell material: Pt crucible; Pt electrodes; freq. range: 2500, 5000 and 10,000 Hz; calibration: 0.01N KCl solution.
Deviations from previous NSRDS recommendations [1, pp. 3,7]			
Ref.	BaCl <sub>2</sub> mol %	Min. departure	
47	100	4.44% (1273 K)	
47	0	0.46% (1273 K)	

<sup>a</sup>Numerical values for pure components at 1273 K.TABLE 33. NaF-BaCl<sub>2</sub>: Specific conductance (ohm<sup>-1</sup>cm<sup>-1</sup>)

BaCl <sub>2</sub> mol %	1123 K	1173 K	1273 K
0			5.13
10	3.67	3.87	4.17
20	2.92	3.16	3.43
30		2.74	2.98
40		2.48	2.70
50			2.54
60			2.44
70			2.34
80			2.30
90			2.24
100			2.18

These values have been interpolated to three significant figures from the graphical presentation of Taniuchi (classical ac technique) [47].

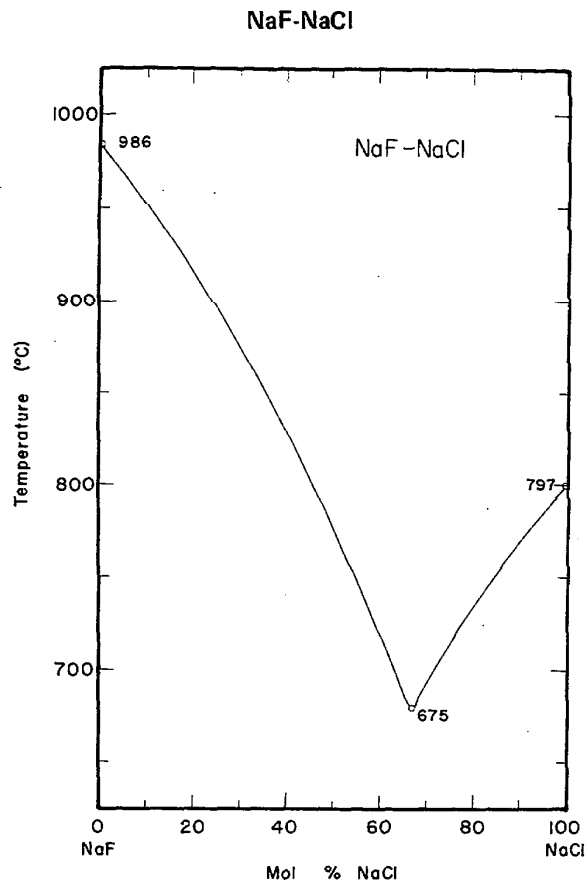


FIGURE 8. Temperature-composition phase diagram for NaF-NaCl.

Argonne National Laboratory, ANL-7316, Galvanic Cells with Fused Electrolytes (1967).

Melt Preparation and Purification

Ohta [63] dried Merck p.a. NaF and NaCl under a vacuum of  $10^{-2}$  torr at a temperature of 400 °C. The salts were then allowed to crystallize as the temperature was slowly lowered. Imperfect crystals were discarded.

Narishkin, Patrov and Chebotarev [87] used chemically pure NaF and NaCl dried to constant weight at 100-150 °C. The salts were then cooled in a desiccator and weighed in sintered corundum containers in an argon atmosphere.

TABLE 34. Density studies: NaF-NaCl

Investigations critically re-examined		
Ref.	NaCl mol %	Temp. range
41 66	0, 25, 50, 75, 100, 30, 50, 75	1173 1273
Comparisons with previous NSRDS recommendations [1, pp. 3 and 4]		
Ref.	NaCl mol %	Departure
41 66	100 0	-1.08% (1173 K) -0.51% (1173 K)

TABLE 35. NaF-NaCl: Density ( $g\ cm^{-3}$ )

T	Mol percent NaCl					
	100	75	50	30	25	0
1173	1.486	1.567	1.663		1.814	1.932
1273		1.5006	1.6452	1.7160		

The values at 1173 K in this table are those of Shieko, Perks and Pozdnyokov (Archimedean method) [41]; those at 1273 K are from Bukhalova, Shegurova and Yagub'yan (Archimedean method) [66]. The data of [41] were reported in equation form; the experimental values of [66] are given. Neither paper gives an error estimate.

TABLE 36. Viscosity studies: NaF-NaCl

Investigations critically re-examined			
Ref.	NaCl mol %	Temp. range (T)	Comments
63	0-100	1273	Pt-10% Ir sphere; tungsten torsion wire; calibration: water, molten $KNO_3$ , NaCl, KCl.

TABLE 37. NaF-NaCl: Viscosity (cp)

Mol % NaCl	1273 K
0	1.420
22	1.185
40	0.990
60	0.863
81	0.76

These values are those of Ohta (oscillating sphere method [63]). Ohta estimated the error in these measurements as  $\pm 2.5\%$ .

TABLE 38. Surface tension studies: NaF-NaCl

Investigations critically re-examined			
Ref.	NaCl mol %	Temp. range (T)	Calibration
87	10-90	1273	Sodium and potassium chlorides and fluorides.

TABLE 39. NaF-NaCl: Surface tension ( $dyn\ cm^{-1}$ )

Mol % NaCl	1273 K
10	162.2
20	134.4
30	125.5
40	121.3
50	115.8
60	116.2
70	111.3
80	110.4
90	108.6

The values in this table are those reported by Narishkin, Patrov and Chebotarev (maximum bubble pressure method) [87].

RbF-RbCl

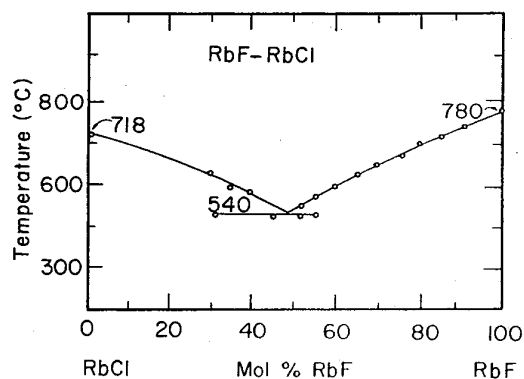


FIGURE 9. Temperature-composition phase diagram for RbF-RbCl. E. I. Banashek, *Izv. Sek. Fiz. Khim. Anal., Akad. Nauk SSSR*, 20, 139 (1950).

Melt Preparation and Purification

Holm and Berge [88] used reagent grade RbF and RbCl. The salts were dried at 400-500 °C under moderate vacuum (0.1-0.01 torr) and then melted in a platinum crucible in an atmosphere of purified  $N_2$ .

TABLE 40. Surface tension studies: RbF-RbCl

Investigations critically re-examined			
Ref.	RbCl Mol %	Temp. range (T)	Comments
88	51	1073	Pt-10% Rh sinker; calibration: water.

TABLE 41. RbF-RbCl: Surface tension (dyn cm<sup>-1</sup>)

Mol % RbCl	1073 K
51	95.1

The value in this table is that reported by Berge and Holm (pin detachment method) [80].

## 5.2. Fluoride-Bromide Systems

## CsF-CsBr

## Melt Preparation and Purification

References [85] and [65], Smirnov et. al, give no information as to melt purification. However, see CsF-CsCl.

TABLE 42. Electrical conductance studies: CsF-CsBr

Investigations critically re-examined			
Ref.	CsBr mol %	Temp. range (T)	Comments
85	0-100	923-1193	Pt electrodes; frequency: 50,000 Hz.

Deviations from previous NSRDS recommendations [1, pp. 3, 15]

Ref.	CsBr mol %	Min. departure	Max. departure
85	100	-0.10% (945 K)	-9.85% (1070 K)
85	0	-1.58% (1010 K)	-4.69% (1125 K)

TABLE 43. CsF-CsBr: Specific conductance (ohm<sup>-1</sup> cm<sup>-1</sup>)

T	Mol percent CsBr								
	100	88	75	63	50	37	25	12	0
930	0.867								
940	0.884								
950	0.901	0.903							
960	0.917	0.923							
970	0.933	0.944		1.137	1.263	1.424		2.006	
980	0.949	0.963		1.154	1.282	1.445	1.701	2.033	
990	0.965	0.982	1.075	1.171	1.301	1.465	1.725	2.060	2.456
1000	0.980	1.001	1.091	1.187	1.319	1.485	1.750	2.087	2.488
1010	0.995	1.019	1.107	1.203	1.337	1.524	1.798	2.139	2.551
1020	1.010	1.037	1.122	1.219	1.354	1.505	1.774	2.139	2.551
1030	1.025	1.053	1.137	1.235	1.371	1.543	1.821	2.164	2.583
1040	1.039	1.070	1.153	1.251	1.388	1.562	1.844	2.189	2.614
1050	1.053	1.086	1.168	1.267	1.404	1.581	1.866	2.214	2.645
1060	1.067	1.101	1.183	1.283	1.420	1.599	1.888	2.238	2.677
1070	1.081	1.116	1.197	1.298	1.435	1.617	1.910	2.262	2.708
1080	1.094	1.313	1.212	1.313	1.450	1.635	1.931	2.285	2.739
1090		1.144	1.226	1.328	1.464	1.652	1.952	2.308	2.770
1100		1.157	1.241	1.343	1.478	1.669	1.972	2.330	2.801
1110		1.170	1.255	1.356	1.492	1.686	1.992	2.352	2.832
1120		1.182	1.268	1.373	1.505	1.703	2.012	2.374	2.863
1130		1.194	1.282	1.387	1.517	1.719	2.031	2.395	2.893
1140		1.205	1.296	1.401	1.530	1.735	2.050	2.415	2.924
1150		1.216	1.309	1.415	1.541	1.751	2.068	2.436	2.955
1160		1.226	1.323	1.429	1.553	1.766	2.086	2.455	2.985
1170		1.235	1.336	1.443	1.564	1.781	2.104	2.475	3.016
1180				1.457					3.046
1190				1.471					

TABLE 43. CsF-CsBr: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )—Continued

Mol % CsBr	Temperature-dependent equations $\kappa = a + bT + cT^2$			Standard deviation
	$-a$	$b \cdot 10^3$	$-c \cdot 10^6$	
0	1.055	3.918	0.375	0.008
12	2.702	6.932	2.143	0.004
25	2.679	6.435	2.006	0.004
37	1.993	4.962	1.484	0.005
50	2.690	6.205	2.196	0.004
63	1.225	3.185	0.773	0.004
75	1.283	3.173	0.799	0.002
88	3.494	7.158	2.663	0.003
100	1.791	4.015	1.244	0.002

These values are based on the work of Smirnov, Shumov, Stepanov, Khokhlov and Noskevich (classical ac technique) [85].

TABLE 44. Density studies: CsF-CsBr

Investigations critically re-examined			
Ref.	CsBr mol %	Temp. range (T)	Comments
85	0-100	923-1073	Pt sphere; calibration: molten $\text{KNO}_3$ .
Deviations from previous NSRDS recommendations [1, pp. 3, 15]			
Ref.	CsBr mol %	Min. departure	Max. departure
85	100	0.03% (1070 K)	0.16% (930 K)
85	0	-0.28% (1070 K)	-0.39% (1010 K)

TABLE 45. CsF-CsBr: Density ( $\text{g cm}^{-3}$ )

T	Mol percent CsBr								
	100	88	75	63	50	37	25	12	0
930	3.112	3.154	3.196	3.242	3.306	3.379	3.469	3.587	3.688
940	3.100	3.141	3.184	3.229	3.293	3.367	3.456	3.573	3.676
950	3.087	3.129	3.171	3.217	3.280	3.354	3.443	3.560	3.663
960	3.075	3.116	3.159	3.204	3.267	3.341	3.430	3.547	3.651
970	3.062	3.104	3.147	3.192	3.255	3.328	3.418	3.534	3.639
980	3.050	3.091	3.134	3.179	3.242	3.316	3.405	3.521	3.627
990	3.037	3.079	3.121	3.167	3.229	3.303	3.392	3.508	3.615
1000	3.025	3.066	3.109	3.154	3.216	3.290	3.379	3.495	3.603
1010	3.012	3.053	3.097	3.142	3.204	3.277	3.366	3.482	3.591
1020	3.000	3.041	3.084	3.129	3.191	3.265	3.353	3.468	3.579
1030	2.987	3.029	3.072	3.117	3.178	3.252	3.340	3.455	3.567
1040	2.975	3.016	3.059	3.104	3.165	3.239	3.327	3.442	3.555
1050	2.962	3.003	3.047	3.092	3.153	3.227	3.315	3.429	3.542
1060	2.950	2.991	3.034	3.079	3.140	3.214	3.302	3.416	3.530
1070	2.937	2.978	3.022	3.067	3.127	3.201	3.289	3.403	3.518

TABLE 45. CsF-CsBr: Density ( $\text{g cm}^{-3}$ )—Continued

Temperature-dependent equations. $\rho = a - bT$			
Mol % CsBr	$a$	$b \cdot 10^3$	Standard deviation
0	4.8135	1.2105	0.0004
12	4.8084	1.3137	0.0007
25	4.6676	1.2885	0.0005
37	4.5614	1.2711	0.0006
50	4.4914	1.2749	0.0006
63	4.4032	1.2488	0.0008
75	4.3567	1.2476	0.0005
88	4.3178	1.2517	0.0006
100	4.2716	1.2468	0.0005

These values are based on the work of Smirnov, Shumov, Stepanov, Khokhlov and Noskevich (Archimedean method) [85]. The following equation, with concentration,  $C$ , in mole percent CsBr and temperature in K, has been derived from the preceding data:  $\rho = a + bT + cC^2 + dTC + eC^3 + fTC^2 + gCT^2$ , where  $a = 4.86120$ ,  $b \cdot 10^3 = -1.25435$ ,  $c \cdot 10^5 = 5.15260$ ,  $d \cdot 10^5 = -2.01680$ ,  $e \cdot 10^7 = -1.94613$ ,  $f \cdot 10^8 = 1.72902$ ,  $g \cdot 10^9 = 9.41693$ , with a maximum departure of 0.28% at 923 K and 12 mol % CsBr, and a standard error of estimate of 0.003. This equation may be used to calculate the density of CsF-CsBr melts at any composition in the temperature range 923-1073 K.

TABLE 46. Viscosity studies: CsF-CsBr

Investigations critically re-examined		
Ref.	CsBr mol %	Temp. range (T)
65 <sup>a</sup>	0-100	See footnote a.

<sup>a</sup>The temperature range was not given. A 1070 K isotherm (molar viscosity versus composition) was reported and the values in the following table were calculated from these data.

TABLE 47. CsF-CsBr: Viscosity (cp)

Mol % CsBr	1070 K
0	1.30 <sub>4</sub>
25	1.22 <sub>4</sub>
37	1.17 <sub>8</sub>
63	1.11 <sub>7</sub>
75	1.12 <sub>2</sub>
88	1.14 <sub>2</sub>
100	1.20 <sub>3</sub>

These values are based on the work of Smirnov, Khokhlov and Antonov (oscillating sphere method) [65] and the density data of Smirnov, Shumov and Khokhlov [83]. The data were reported in equation form and no estimate of error was given.

TABLE 48. CsF-CsBr: Molar viscosity ( $\text{erg s mol}^{-1}$ )<sup>a</sup>

Temperature-dependent equations $\log \eta_M = A + B/T$		
Mol % CsBr	$-A$	$B$
0	1.6660	1516
25	1.3296	1202
37	1.2840	1168
63	0.9267	821
75	0.9464	869
88	1.2039	985
100	1.0230	1031

Equations as reported by Smirnov, Khokhlov and Antonov [65] (see footnote, table 46); of limited value since temperature limits of applicability and standard deviation were not reported.

<sup>a</sup>Molar viscosity is defined by  $\eta(M\rho^{-1})$  where  $M = X_1M_1 + X_2M_2$ , and  $\rho$ ,  $X_1$ ,  $X_2$ , are the density and mol fraction composition of the molten mixture, with the units of  $\eta$  in poise.

## KF-KBr

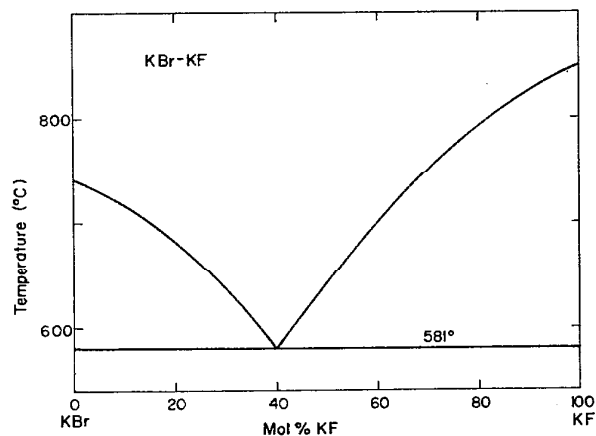


FIGURE 10. Temperature-composition phase diagram for KBr-KF. N. S. Kurnakow and J. B. Wrzesnewsky, Z. Anorg. Chem. 74, 90 (1912).



Melt Preparation and Purification

Smirnov et al. [84] used high purity potassium halides. Anhydrous KF was obtained by dehydrating  $\text{KF}\cdot 2\text{H}_2\text{O}$ .

TABLE 49. Electrical conductance studies: KF-KBr

Investigations critically re-examined			
Ref.	KBr mol %	Temp. range (T)	Comments
84	0-100	1003-1293	Pt electrodes; freq. range: 50,000 Hz.
Deviations from previous NSRDS recommendations [1, pp. 3,14]			
Ref.	KBr mol %	Min. departure	Max. departure
84	100	-2.69% (1220 K)	-4.92% (1100 K)
84	0	-7.44% (1155% K)	-7.64% (1220 K)

TABLE 50. KF-KBr: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

T	Mol percent KBr								
	100	88	75	63	50	37	25	12	0
1010				1.824					
1020		1.708		1.845					
1030	1.602	1.731	1.795	1.865					
1040	1.625	1.753	1.817	1.886					
1050	1.647	1.775	1.838	1.906					
1060	1.669	1.796	1.859	1.927		2.167			
1070	1.691	1.817	1.879	1.947		2.188			
1080	1.712	1.837	1.900	1.968		2.210			
1090	1.733	1.856	1.919	1.988		2.231	2.397		
1100	1.753	1.875	1.939	2.009	2.090	2.252	2.423		
1110	1.774	1.893	1.958	2.029	2.115	2.273	2.449	2.763	
1120	1.794	1.911	1.977	2.050	2.140	2.294	2.475	2.791	
1130	1.814	1.928	1.996	2.071	2.165	2.315	2.500	2.820	
1140	1.833	1.945	2.014	2.091	2.189	2.336	2.525	2.848	
1150	1.852	1.961	2.032	2.112	2.212	2.357	2.550	2.876	
1160	1.871	1.976	2.050	2.133	2.235	2.378	2.575	2.904	3.375
1170	1.890	1.991	2.067	2.153	2.258	2.398	2.599	2.932	3.395
1180	1.908	2.006	2.084	2.174	2.280	2.419	2.622	2.960	3.426
1190	1.926	2.019	2.101	2.195	2.301	2.439	2.646	2.987	3.453
1200	1.944	2.033	2.117	2.216	2.322	2.460	2.669	3.015	3.481
1210	1.961	2.045	2.133	2.237	2.343	2.480	2.692	3.042	3.509
1220	1.978	2.058	2.149	2.258	2.363	2.501	2.714	3.069	3.537
1230		2.069	2.164		2.383	2.521	2.737	3.096	3.565
1240		2.080	2.179		2.402	2.541	2.758	3.123	3.594
1250		2.091	2.194		2.420	2.561	2.780	3.150	3.622
1260			2.208		2.439	2.581	2.801	3.176	3.651
1270						2.601	2.822	3.203	3.681
1280								3.229	
1290								3.255	

Temperature-dependent equation  
 $\kappa = a + bT + cT^2$

Mol % KBr	-a	$b \cdot 10^3$	$-c \cdot 10^6$	Standard deviation
0	-2.660	-1.392	-1.730	0.012
12	1.359	4.557	0.760	0.007
25	2.417	6.180	1.618	0.008
37	0.513	2.913	0.363	0.006
50	3.699	7.953	2.446	0.005
63	0.112	1.796	-0.120	0.005
75	2.144	5.484	1.611	0.004
88	3.559	8.021	2.801	0.005
100	2.343	5.395	1.519	0.003

These values are based on the work of Smirnov, Shumov, Khokhlov, Stepanov, Noskevich and Antonenko (classical ac technique) [84].

TABLE 51. Density studies: KF-KBr

Investigations critically re-examined			
Ref.	KBr mol %	Temp. range (T)	Comments
84	0-100	873-1253	Pt ball; calibration: molten KNO <sub>3</sub> .
Deviations from previous NSRDS recommendations [1, pp. 3,14]			
Ref.	KBr mol %	Min. departure	Max. departure
84	100	0.35% (1140 K)	0.38% (1020 K)
84	0	0.36% (1150 K)	1.91% (1250 K)

TABLE 52. KF-KBr: Density (g cm<sup>-3</sup>)

T	Mol percent KBr								
	100	88	75	63	50	37	25	12	0
980						2.066			
990					2.075	2.058			
1000					2.068	2.051			
1010	2.133				2.060	2.043			
1020	2.124				2.052	2.036			
1030	2.116				2.044	2.028			
1040	2.108				2.037	2.021	2.008		
1050	2.099				2.029	2.013	2.001		
1060	2.091				2.021	2.006	1.993		
1070	2.083				2.014	1.999	1.979		
1080	2.074		2.040	2.021	2.006	1.991	1.979		
1090	2.066	2.054	2.032	2.013	1.998	1.984	1.971	1.957	
1100	2.058	2.046	2.024	2.005	1.991	1.976	1.964	1.950	
1110	2.049	2.038	2.016	1.997	1.983	1.969	1.957	1.943	
1120	2.041	2.030	2.008	1.989	1.975	1.961	1.950	1.936	
1130	2.033	2.022	2.001	1.982	1.967	1.954	1.942	1.929	
1140	2.024	2.013	1.993	1.974	1.960		1.935	1.922	
1150		2.005	1.985	1.966	1.952		1.928	1.915	1.904
1160		1.997	1.977	1.958				1.908	1.898
1170		1.989	1.969	1.950				1.901	1.891
1180		1.981	1.961	1.942				1.894	1.884
1190		1.973	1.954	1.935				1.887	1.877
1200		1.964	1.946	1.927				1.880	1.871
1210		1.956	1.938	1.919					1.864
1220		1.948	1.930	1.911					1.857
1230			1.922	1.903					1.850
1240				1.895					1.844
1250									1.837

TABLE 52. KF-KBr: Density ( $\text{g cm}^{-3}$ )—Continued

Temperature-dependent equations $\rho = a - bT$			
Mol % KBr	$a$	$b \cdot 10^3$	Standard deviation
0	2.6806	0.6750	0.0002
12	2.7232	0.7030	0.0003
25	2.7657	0.7286	0.0003
37	2.7956	0.7448	0.0004
50	2.8378	0.7702	0.0006
63	2.8691	0.7853	0.0005
75	2.8841	0.7819	0.0005
88	2.9464	0.8184	0.0004
100	2.9740	0.8329	0.0009

These values are based on the work of Smirnov, Shumov, Khokhlov, Stepanov, Noskevich and Antonenko (Archimedean method) [84]. The following equation, with concentration,  $C$ , in mole percent KBr and temperature in K, has been derived from the preceding data:  $\rho = a + bC + cT^2 + dTC^2 + eT^3 + fCT^2$ , where  $a = 2.47777$ ,  $b \cdot 10^3 = 1.47828$ ,  $c \cdot 10^7 = -6.83004$ ,  $d \cdot 10^9 = 3.70657$ ,  $e \cdot 10^{10} = 2.17657$ ,  $f \cdot 10^{10} = -5.69776$ , with a maximum departure of 0.22% at 1083 K and 88 mol % KBr, and a standard error of estimate of 0.002. This equation may be used to calculate the density of KF-KBr melts at any given composition in the temperature range 873-1253 K.

LiF-LiBr

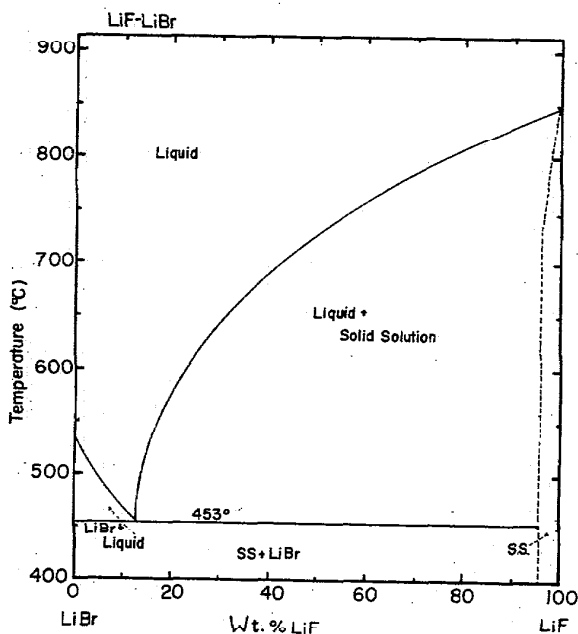


FIGURE 11. Temperature-composition phase diagram for LiF-LiBr.

A. A. Botschwar, Z. Anorg. Allg. Chem. 210, 163 (1933).

Melt Preparation and Purification

References [79] and [82], Smirnov et al., contain no information on melt purification. However, see CsF-CsCl.

TABLE 53. Electrical conductance studies: LiF-LiBr

Ref.	LiBr mol %	Temp. range (T)	Comments
82	0-100	873-1283	Pt electrodes; freq. range: 50,000 Hz.
Deviations from previous NSRDS recommendations [1, pp. 3,14]			
Ref.	LiBr mol %	Min. departure	Max. departure
82	100	0.02% (915 K)	-2.08% (1020 K)
82	0	0.03% (1260 K)	-2.56% (1150 K)

TABLE 54. LiF-LiBr: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

T	Mol percent LiBr								
	100	88	75	63	50	37	25	12	0
880	5.058	4.274	3.415	3.158	3.076	3.075	4.009	4.600	6.131
900	5.139	4.357	3.511	3.257	3.197	3.223	4.147	4.784	6.328
920	5.218	4.437	3.605	3.353	3.315	3.370	4.281	4.967	6.521
940	5.295	4.514	3.696	3.447	3.432	3.516	4.412	5.148	6.709
960	5.369	4.589	3.785	3.539	3.547	3.661	4.542	5.327	6.894
980	5.441	4.660	3.871	3.629	3.660	3.805	4.668	5.503	7.074
1000	5.511	4.728	3.955	3.716	3.771	3.948	4.791	5.677	7.250
1020	5.578	4.794	4.036	3.801	3.881	4.089	4.911	5.849	7.422
1040	5.642	4.857	4.116	3.884	3.989	4.228	5.029	6.018	7.590
1060	5.704	4.918	4.192	3.965	4.094	4.366	5.143	6.183	7.754
1080	5.763	4.975	4.267	4.043	4.198	4.503	5.255	6.346	7.914
1100	5.818	5.030	4.339	4.120	4.300	4.637	5.364	6.506	8.069
1120	5.871	5.082	4.408	4.194	4.400	4.770	5.470	6.662	8.221
1140	5.920	5.133	4.475	4.266	4.450	4.901	5.574	6.815	8.368
1160	5.966	5.180	4.540	4.335	4.593	5.029	5.674	6.964	8.511
1180	6.008	5.226	4.602	4.402	4.686	5.156	5.772	7.110	8.650
1200	6.046	5.268	4.662	4.468	4.777	5.280	5.866	7.252	8.785
1220	6.081	5.309	4.720	4.531	4.866	5.402	5.958	7.389	8.916
1240	6.122	5.347	4.775	4.591	4.952	5.522	6.047	7.523	9.043
1260	6.138	5.383	4.828	4.650	5.036	5.639	6.133	7.652	9.166
1280	6.161	5.417	4.879	4.706	5.118	5.753	6.217	7.777	9.284

Temperature-dependent equations

$$\kappa = a + bT + cT^2 + dT^3$$

Mol % LiBr	a	b · 10 <sup>3</sup>	c · 10 <sup>6</sup>	d · 10 <sup>9</sup>	Standard Error of estimate
100	1.35534	2.38932	4.26653	-2.52079	0.018%
88	-3.08073	13.2314	-6.39220	0.976343	0.021%
75	-3.24985	10.3448	-3.21006	0.077853	0.028%
63	-3.37401	9.86628	-2.77621		0.038%
50	-3.16662	7.44947	0.388531	-0.941942	0.026%
37	-2.98903	4.88492	3.95182	-1.91644	0.033%
25	-4.85468	13.2030	-3.55740		0.023%
12	-3.18689	6.09129	5.77301	-3.00310	0.11%
0	-6.61583	19.0245	-515839		0.023%

These values are based on the work of Smirnov, Khokhlov, Stepanov, and Shumov (classical ac technique) [82] and were calculated from the reported values of equivalent conductivity and density.

TABLE 55. Density studies: LiF-LiBr

Investigations critically re-examined			
Ref.	LiBr mol %	Temp. range (T)	Comments
82	0-100	873-1283	Pt sphere; calibration: molten KNO <sub>3</sub> .
Deviations from previous NSRDS recommendations [1, pp. 3,14]			
Ref.	LiBr mol %	Min. departure	Max. departure
82	100	-0.30% (1020 K)	-0.47% (830 K)
82	0	0.01% (1210 K)	0.31% (1280 K)

TABLE 56. LiF-LiBr: Density (g cm<sup>-3</sup>)

T	Mol percent LiBr								
	100	88	75	63	50	37	25	12	0
800	2.481	2.442	2.384	2.333	2.280	2.210	2.138	2.035	1.902
900	2.469	2.429	2.373	2.321	2.269	2.200	2.128	2.026	1.893
920	2.456	2.417	2.361	2.310	2.258	2.190	2.118	2.017	1.885
940	2.444	2.405	2.350	2.299	2.247	2.180	2.107	2.007	1.877
960	2.431	2.393	2.338	2.288	2.236	2.169	2.097	1.998	1.869
980	2.419	2.380	2.327	2.277	2.225	2.159	2.087	1.989	1.860
1000	2.406	2.368	2.315	2.266	2.214	2.149	2.077	1.980	1.852
1020	2.393	2.356	2.303	2.255	2.203	2.139	2.067	1.971	1.844
1040	2.381	2.343	2.292	2.244	2.192	2.129	2.057	1.962	1.835
1060	2.368	2.331	2.280	2.233	2.181	2.118	2.046	1.952	1.827
1080	2.356	2.319	2.269	2.222	2.070	2.108	2.036	1.943	1.819
1100	2.343	2.307	2.257	2.211	2.159	2.098	2.026	1.935	1.811
1120	2.331	2.294	2.246	2.199	2.148	2.088	2.016	1.925	1.802
1140	2.318	2.282	2.234	2.188	2.137	2.077	2.006	1.916	1.794
1060	2.305	2.270	2.223	2.177	2.126	2.067	1.995	1.907	1.786
1080	2.293	2.257	2.211	2.166	2.115	2.057	1.985	1.897	1.777
1200	2.280	2.245	2.199	2.155	2.104	2.047	1.975	1.888	1.769
1220	2.268	2.233	2.188	2.144	2.093	2.037	1.965	1.879	1.761
1240	2.255	2.220	2.176	2.133	2.082	2.026	1.955	1.870	1.753
1260	2.243	2.208	2.165	2.122	2.071	2.016	1.945	1.861	1.744
1280	2.230	2.196	2.153	2.111	2.060	2.006	1.934	1.851	1.736

Temperature-dependent equations

$$\rho = a + bT$$

Mol % LiBr	a	b · 10 <sup>3</sup>	Standard deviation
0	2.266	0.414	0.002
12	2.439	0.459	0.004
25	2.586	0.509	0.004
37	2.660	0.511	0.005
50	2.763	0.549	0.004
63	2.821	0.555	0.004
75	2.893	0.578	0.004
88	2.983	0.615	0.005
100	3.034	0.628	0.004

These values are based on the work of Smimov, Khokhlov, Stepanov and Shumov (modified maximum bubble pressure method) [82]. The following equation, with concentration, C, in mole percent LiBr and temperature in K, has been derived from the preceding data:  $\rho = a + bC + cT + dC^2 + eC^3 + fTC^2 + gCT^2$ , where  $a = 2.29126$ ,  $b \cdot 10^2 = 1.17976$ ,  $c \cdot 10^4 = 4.34204$ ,  $d \cdot 10^5 = -9.40849$ ,  $e \cdot 10^7 = 3.97207$ ,  $f \cdot 10^9 = 1.72173$ ,  $g \cdot 10^{10} = -9.99427$ , with a maximum departure of 0.40% at 873 K and 0.0 mol % LiBr, and a standard error of estimate of 0.004. This equation may be used to calculate the density of LiF-LiBr melts at any concentration in the temperature range 873-1283 K.

TABLE 57. Surface tension studies: LiF-LiBr

Investigations critically re-examined			
Ref.	LiBr mol %	Temp. range (T)	Comments
79	0-100	884-1290	Cell material: molybdenum crucible; calibration: molten NaCl.
Deviations from previous NSRDS recommendations [2, p. 55]			
Ref.	LiBr mol %	Min. departure	Max. departure
79	0	1.70% (1170 K)	1.76% (1240 K)

TABLE 58. LiF-LiBr: Surface tension (dyn cm<sup>-1</sup>)

T	Mol percent LiBr								
	100	88	75	63	50	37	25	12	0
890	123.7		142.0						
900	123.0	130.9	141.2						
910	122.3	130.1	140.5						
920	121.6	129.4	139.7						
930	120.9	128.7	138.9	150.5					
940	120.2	127.9	138.2	149.7					
950	119.5	127.2	137.4	148.9					
960	118.9	126.5	136.6	148.1	162.5				
970	118.2	125.8	135.9	147.3	161.7				
980	117.5	125.1	135.1	146.5	160.9				
990	116.8	124.3	134.4	145.7	160.1				
1000	116.1	123.6	133.6	144.9	159.3				
1010	115.4	122.9	132.8	144.1	158.5				
1020	114.7	122.1	132.1	143.3	157.7	175.5			
1030	114.0	121.4	131.3	142.5	156.9	174.6			
1040	113.3	120.7	130.5	141.7	156.1	173.8			
1050	112.6	120.0	129.8	140.9	155.3	172.9			
1060	111.9	119.3	129.0	140.1	154.4	172.0			
1070	111.3	118.5	128.3	139.3	153.6	171.2			
1080	110.6	117.8	127.5	138.5	152.8	170.3	189.2		
1090	109.9	117.1	126.7	137.7	152.0	169.5	188.3		
1100	109.2	116.3	126.0	136.9	151.2	168.6	187.4		241.7
1110	108.5	115.6	125.2	136.1	150.4	167.7	186.5	211.2	240.7
1120	107.8	114.9	124.5	135.3	149.6	166.9	185.6	210.2	239.8
1130	107.1	114.2		134.5	148.8	166.0	184.7	209.2	238.8
1140				133.7	148.0	165.2	183.8	208.3	237.8
1150					147.1	164.3	182.9	207.3	236.8
1160					146.3	163.4	182.0	206.4	235.8
1170					145.5	162.6	181.1	205.4	234.8
1180					144.7	161.7	180.3	204.5	233.9
1190					143.9	160.9	179.3	203.5	232.9
1200					143.1	160.0	178.5	202.6	231.9
1210					142.3	159.1	177.6	201.6	230.9
1220						158.3	176.7	200.7	229.9
1230						157.4	175.8	199.7	228.9
1240						156.6	174.9	198.7	227.9
1250						155.7	174.0	197.8	226.9
1260							173.1	196.8	226.0
1270							172.2	195.9	225.0
1280								194.9	224.0
1290									223.0

Temperature-dependent equations

$$\gamma = a - bT$$

Mol % LiBr	a	b
0	350.2	0.0986
12	316.8	0.0952
25	286.1	0.0897
37	263.2	0.0860
50	240.3	0.0810
63	224.6	0.0797
75	209.8	0.0762
88	196.1	0.0725
100	185.2	0.0691

These values are based on the work of Smirnov and Stepanov (maximum bubble pressure method) [79]. The data were reported in equation form. No error estimate was given.

5.3. Fluoride-iodide Systems

CsF-CsI

Melt Preparation and Purification

Neither [65] nor [85], Smirnov et al., give information on melt preparation. However, see CsF-CsCl.

TABLE 59. Electrical conductance studies: CsF-CsI

Investigations critically re-examined			
Ref.	CsI mol %	Temp. range (T)	Comments
85	0-100	923-1183	Pt electrodes; freq. range: 50,000 Hz.

Deviations from previous NSRDS recommendations [1, pp. 3,20]			
Ref.	CsI mol %	Min. departure	Max. departure
95	100	-0.54% (985 K)	-12.84% (1070 K)
85	0	-1.58% (1910 K)	-4.92% (1125 K)

TABLE 60. CsF-CsI: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

T	Mol percent CsI								
	100	88	75	63	50	37	25	12	0
930	0.707								
940	0.721								
950	0.734	0.755	0.807						
960	0.747	0.769	0.821	0.895		1.147	1.351		
970	0.759	0.783	0.835	0.910		1.165	1.370		
980	0.772	0.796	0.848	0.926	1.031	1.183	1.390		
990	0.785	0.810	0.861	0.941	1.047	1.201	1.409	1.716	2.456
1000	0.797	0.823	0.874	0.956	1.062	1.219	1.428	1.738	2.488
1010	0.809	0.836	0.887	0.971	1.077	1.236	1.447	1.760	2.520
1020	0.821	0.849	0.900	0.985	1.092	1.253	1.466	1.782	2.551
1030	0.833	0.862	0.912	1.000	1.107	1.270	1.485	1.804	2.583
1040	0.845	0.975	0.925	1.014	1.212	1.286	1.503	1.825	2.614
1050	0.857	0.888	0.937	1.028	1.135	1.302	1.522	1.847	2.645
1060	0.869	0.907	0.949	1.042	1.149	1.318	1.541	1.868	2.677
1070	0.880	0.913	0.962	1.055	1.163	1.333	1.559	1.889	2.708
1080		0.926	0.974	1.069	1.177	1.349	1.577	1.910	2.739
1090		0.938	0.985	1.082	1.190	1.363	1.593	1.930	2.770
1100		0.951	0.997	1.095	1.203	1.378	1.613	1.951	2.801
1110		0.963	1.009	1.107	1.216	1.392	1.631	1.971	2.832
1120		0.975	1.021	1.120	1.229	1.406	1.649	1.991	2.863
1130				1.132	1.242	1.420	1.667	2.011	2.893
1140				1.144	1.254	1.433	1.685	2.031	2.924
1150				1.156	1.266	1.446	1.702	2.051	2.955
1160				1.168	1.278	1.459	1.720	2.071	2.985
1170				1.179	1.290	1.471	1.737	2.090	3.016
1180								2.109	3.046

Temperature-dependent equations  
 $\kappa = a + bT + cT^2$

Mol % CsI	-a	b · 10 <sup>3</sup>	-c · 10 <sup>6</sup>	Standard deviation
0	1.055	3.918	0.375	0.008
12	1.331	3.923	0.854	0.005
25	0.990	2.930	0.512	0.004
37	2.026	4.749	1.504	0.003
50	1.512	3.629	1.055	0.002
63	1.586	3.592	1.050	0.001
75	1.057	2.565	0.634	0.003
88	0.987	2.296	0.486	0.004
100	1.081	2.523	0.645	0.001

These values are based on the work of Smirnov, Shumov, Stepanov, Khokhlov and Noskevich (classical ac technique) [85].

TABLE 61. Density studies: CsF-CsI

Investigations critically re-examined			
Ref.	CsI mol %	Temp. range (T)	Comments
85	0-100	923-1073	Pt sphere; calibration: molten KNO <sub>3</sub> .
Deviations from previous NSRDS recommendations [1, pp. 3, 20]			
Ref.	CsI mol %	Min. departure	Max. departure
85	100	0.50% (1070 K)	0.94% (930 K)
85	0	-0.28% (1070 K)	-0.39% (1010 K)

TABLE 62. CsF-CsI: Density (g cm<sup>-3</sup>)

T	Mol percent CsI								
	100	88	75	63	50	37	25	12	0
930	3.170	3.185	3.219	3.250	3.295	3.363	3.461	3.577	3.688
940	3.157	3.172	3.206	3.237	3.282	3.350	3.448	3.563	3.676
950	3.144	3.160	3.193	3.224	3.269	3.337	3.435	3.550	3.663
960	3.131	3.147	3.180	3.211	3.257	3.324	3.422	3.537	3.651
970	3.118	3.135	3.167	3.198	3.244	3.311	3.409	3.524	3.639
980	3.105	3.122	3.154	3.185	3.231	3.298	3.396	3.511	3.627
990	3.093	3.110	3.141	3.172	3.218	3.285	3.383	3.498	3.615
1000	3.080	3.097	3.128	3.159	3.205	3.273	3.370	3.485	3.603
1010	3.067	3.085	3.115	3.146	3.192	3.260	3.357	3.472	3.591
1020	3.054	3.072	3.102	3.133	3.179	3.247	3.344	3.459	3.579
1030	3.041	3.060	3.089	3.120	3.166	3.234	3.331	3.445	3.567
1040	3.028	3.047	3.076	3.107	3.153	3.221	3.318	3.432	3.555
1050	3.015	3.035	3.063	3.094	3.140	3.208	3.305	3.419	3.542
1060	3.002	3.022	3.049	3.081	3.127	3.195	3.292	3.406	3.530
1070	2.989	3.010	3.036	3.068	3.114	3.182	3.279	3.393	3.518

Temperature-dependent equations

$$\rho = a - bT$$

Mol % CsI	a	b · 10 <sup>3</sup>	Standard deviation
0	4.8135	1.2105	0.0004
12	4.7959	1.3110	0.0008
25	4.6753	1.3052	0.0006
37	4.5627	1.2901	0.0006
50	4.4988	1.2940	0.0006
63	4.4598	1.3010	0.0006
75	4.4337	1.3058	0.0005
88	4.3478	1.2506	0.0006
100	4.3677	1.2880	0.0007

These values are based on the work of Smirnov, Shumov, Stepanov, Khokhlov and Noskevich (Archimedean method) [85]. The following equation, with concentration, C, in mole percent CsI and temperature in K, has been derived from the preceding data:  $\rho = a + bT + cT^2 + dTC + eC^3 + fTC^2 + gCT^2$ , where  $a = 4.85201$ ,  $b \cdot 10^3 = -1.24454$ ,  $c \cdot 10^5 = 6.13518$ ,  $d \cdot 10^5 = -2.09668$ ,  $e \cdot 10^7 = -2.25767$ ,  $f \cdot 10^8 = 2.64349$ ,  $g \cdot 10^9 = 9.16775$ , with a maximum departure of 0.30% at 923 K and 37 mol % CsI, and a standard error of estimate of 0.004. This equation may be used to calculate the density of CsF-CsI melts at any composition in the temperature range 923-1073 K.



TABLE 63. Viscosity studies: CsF-CsI

Investigations critically re-examined		
Ref.	CsI mol %	Temp. range
65	0-100	See footnote a.

<sup>a</sup>The temperature range was not given. The isotherm at 1070 K (molar viscosity vs. composition) was reported and the values in the following table were calculated from these data.

TABLE 64. CsF-CsI: Viscosity (cp)

Mol % CsI	1070 K
0	1.30 <sub>4</sub>
12	1.26 <sub>4</sub>
37	1.09 <sub>1</sub>
50	1.03 <sub>8</sub>
63	0.975
75	0.998
88	1.03 <sub>0</sub>
100	1.01 <sub>1</sub>

These values were calculated from the data of Smirnov, Khokhlov and Antonov (oscillating sphere method) [65], and the density data of Smirnov, Shumov and Khokhlov [83]. The data were reported in equation form and no estimate of error was given.

TABLE 65. CsF-CsI: Molar viscosity (erg s mol<sup>-1</sup>)<sup>a</sup>

Temperature-dependent equations $\log \eta_M = A + B/T$		
Mol % CsI	-A	B
0	1.6660	1516
12	1.5893	1474
37	1.1203	1004
50	1.0130	909
63	1.1284	1041
75	1.0525	1002
88	0.9461	934
100	0.9142	918

Equations as reported by Smirnov et al. [65]. Of limited usefulness since the temperature ranges to which they pertain and standard deviation were not reported.

<sup>a</sup>Molar viscosity is defined by  $\eta(M\rho^{-1})$  where  $M = X_1M_1 + X_2M_2$ , and  $\rho$ ,  $X_1$ ,  $X_2$ , are the density and mol fraction composition of the molten mixture, with the units of  $\eta$  in poise.

KF-KI

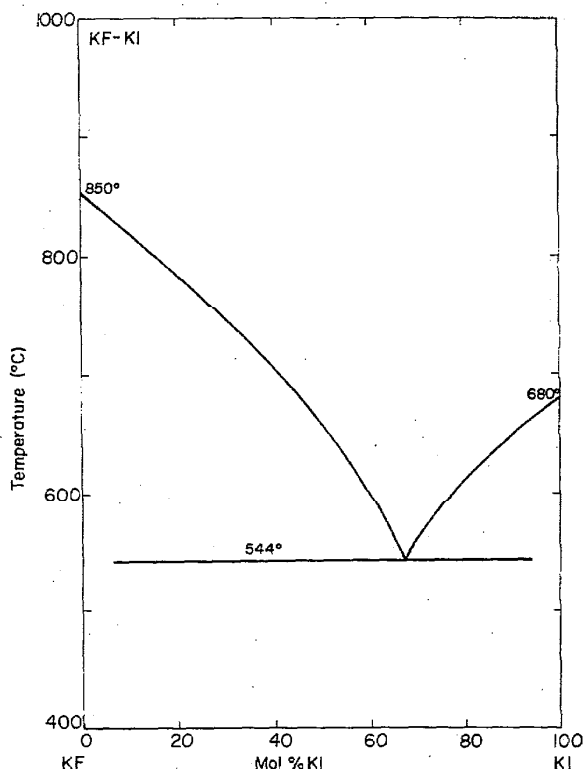


FIGURE 12. Temperature composition phase diagram for KF-KI.

A. G. Bergman and F. P. Platonov. *Izv. Sek. Fiz. Khim. Anal. Inst. Obshch. Neorg. Khim., Akad Nauk SSSR* 11, 256 (1938).

Melt Preparation and Purification

Smirnov et al. [84] used high purity potassium iodide. Anhydrous KF was prepared from the dihydrate.

TABLE 66. Electrical conductance studies: KF-KI

Investigations critically re-examined			
Ref.	KI mol %	Temp. range (T)	Comments
84	0-100	963-1313	Pt electrodes; freq. range: 50,000 Hz.

Deviations from previous NSRDS recommendations [1, pp. 3,19]			
Ref.	KI mol%	Min. departure	Max. departure
84	100	0.02% (1045 K)	4.17% (965 K)
84	0	-7.44% (1155 K)	-7.64% (1220 K)

TABLE 67. KF-KI: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

T	Mol percent KI								
	100	88	75	63	50	37	25	12	0
970	1.338								
980	1.357	1.247	1.293						
990	1.376	1.271	1.316						
1000	1.394	1.295	1.338	1.374					
1010	1.412	1.318	1.360	1.398					
1020	1.429	1.341	1.382	1.423					
1030	1.447	1.364	1.404	1.447	1.574				
1040	1.463	1.386	1.426	1.471	1.598	1.708			
1050	1.480	1.407	1.447	1.494	1.621	1.733			
1060	1.496	1.429	1.469	1.517	1.644	1.757			
1070	1.511	1.449	1.490	1.541	1.667	1.780			
1080	1.527	1.470	1.512	1.563	1.689	1.804			
1090	1.541	1.480	1.533	1.586	1.711	1.827			
1100	1.556	1.509	1.554	1.609	1.732	1.850			
1110	1.570	1.528	1.575	1.631	1.753	1.873	2.143		
1120	1.584	1.546	1.596	1.653	1.773	1.896	2.165	2.580	
1130	1.597	1.565	1.617	1.675	1.793	1.918	2.186	2.611	
1140	1.610	1.582	1.638	1.696	1.813	1.940	2.208	2.642	
1150	1.622	1.599	1.658	1.718	1.832	1.962	2.230	2.673	
1160	1.635	1.616	1.679	1.739	1.851	1.984	2.251	2.703	3.373
1170	1.646	1.632	1.699	1.760	1.869	2.005	2.273	2.733	3.399
1180	1.658	1.648	1.719	1.781	1.888	2.026	2.294	2.763	3.426
1190		1.663	1.739	1.801	1.905	2.047	2.316	2.793	3.453
1200		1.678	1.759		1.923	2.068	2.337	2.823	3.481
1210			1.779		1.939	2.089	2.358	2.853	3.509
1220			1.799		1.956	2.109	2.380	2.883	3.537
1230					1.972	2.129	2.401	2.912	3.565
1240					1.987	2.149	2.422	2.942	3.594
1250					2.003	2.168	2.443	2.971	3.623
1260					2.017	2.188	2.464	3.000	3.656
1270					2.032	2.207	2.485	3.029	3.682
1280					2.046	2.226	2.506	3.057	
1290						2.244	2.527	3.086	
1300							2.548	3.115	
1310							2.569		

## Temperature-dependent equations

$$\kappa = a + bT + cT^2$$

Mol % KI	-a	$b \cdot 10^3$	$-c \cdot 10^6$	Standard deviation
0	-2.660	-1.392	-1.730	0.012
12	1.762	4.660	0.699	0.007
25	0.588	2.740	0.252	0.006
37	2.087	4.863	1.167	0.004
50	3.021	6.534	2.012	0.006
63	2.198	4.685	1.113	0.004
75	1.420	3.300	0.542	0.004
88	3.306	6.838	2.237	0.004
100	2.355	5.685	1.936	0.002

These values are based on the work of Smirnov, Shumov, Khokhlov, Stepanov, Noskevich and Antonenko (classical ac technique) [84].

TABLE 68. Density studies: KF-KI

Ref.	KI mol %	Temp. range (T)	Comments
84	0-100	1003-1253	Pt ball; calibration: molten KNO <sub>3</sub> .
Deviations from previous NSRDS recommendation [1, pp. 3,19]			
Ref.	KI mol %	Min. departure	Max. departure
84	100	0.38% (1090 K)	0.45% (1005 K)
84	0	0.36% (1150 K)	1.91% (1250 K)

TABLE 69. KF-KI: Density (g cm<sup>-3</sup>)

T	Mol percent KI								
	100	88	75	63	50	37	25	12	0
1010	2.405	2.368							
1020	2.395	2.359			2.236				
1030	2.385	2.350			2.223				
1040	2.375	2.340			2.219	2.172			
1050	2.365	2.331	2.290		2.211	2.164			
1060	2.356	2.322	2.281		2.203	2.156	2.106		
1070	2.346	2.312	2.272		2.194	2.148	2.098		
1080	2.336	2.303	2.263	2.229	2.186	2.140	2.091		
1090	2.326	2.294	2.254	2.220	2.177	2.132	2.083		
1100		2.285	2.245	2.211	2.169	2.124	2.075	2.013	
1110		2.275	2.236	2.203	2.161	2.116	2.067	2.006	
1120		2.266	2.227	2.194	2.152	2.108	2.060	1.999	
1130		2.257	2.218	2.185	2.144	2.100	2.052	1.991	
1140			2.209	2.176	2.136	2.092	2.044	1.984	
1150			2.201	2.168	2.127	2.084	2.036	1.977	1.904
1160			2.192	2.159		2.076	2.029	1.970	1.898
1170			2.183	2.150		2.068	2.021	1.963	1.891
1180				2.141		2.060	2.013	1.955	1.884
1190						2.052	2.005	1.948	1.877
1200								1.941	1.877
1210								1.933	1.864
1220								1.926	1.857
1230									1.850
1240									1.844
1250									1.867

Temperature-dependent equations

$$\rho = a - bT$$

Mol % KI	a	b · 10 <sup>3</sup>	Standard deviation
0	2.6806	0.6750	0.0002
12	2.8122	0.7262	0.0005
25	2.9281	0.7754	0.0003
37	3.0044	0.8001	0.0004
50	3.0887	0.8359	0.0003
63	3.1716	0.8729	0.0004
75	3.2247	0.8905	0.0004
88	3.3108	0.9330	0.0003
100	3.3927	0.9782	0.0005

These values are based on the work of Smirnov, Shumov, Stepanov, Khokhlov, Noskevich and Antonenko (Archimedean method) [84]. The following equation, with concentration, C, in mole percent KI and temperature in K, has been derived from the preceding data:  $\rho = a + bC + cT^2 + dC^3 + eTC^2 + fT^3$ , where  $a = 2.45700$ ,  $b \cdot 10^3 = 5.94014$ ,  $c \cdot 10^7 = -6.01598$ ,  $d \cdot 10^7 = 1.27720$ ,  $e \cdot 10^8 = -3.21815$ ,  $f \cdot 10^{10} = 1.62975$ , with a maximum departure of 0.28% at 1143 K and 0.0 mol % KI, and a standard error of estimate of 0.002. This equation may be used to calculate the density of KF-KI melts at any composition in the temperature range 1003-1253 K.

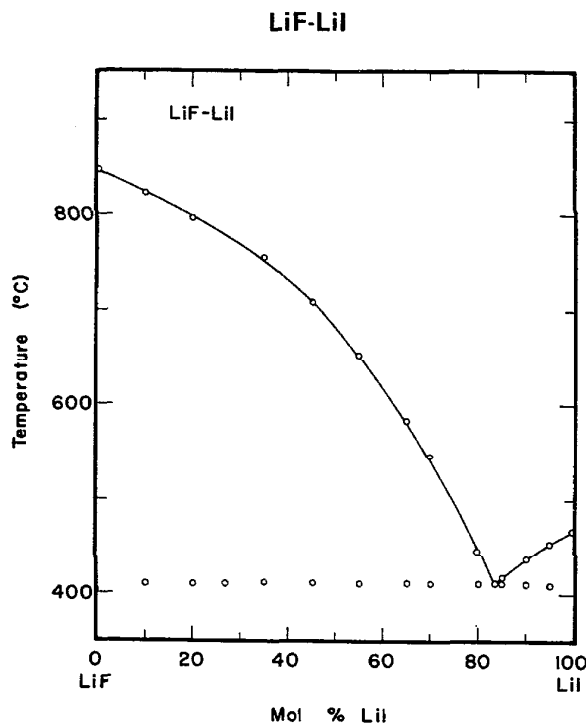


FIGURE 13. Temperature-composition phase diagrams for LiF-LiI.

Argonne National Laboratory, ANL-7316, Galvanic Cells With Fused Electrolytes (1967).

### Melt Preparation and Purification

Johnson [303] used reagent-grade LiI purified by bubbling anhydrous HI through the molten salt to remove the last traces of water. Single-crystal LiF was used without further purification.

Smirnov et al. [79,82] gave no details on melt preparation and purification. However, see CsF-CsCl.

TABLE 70. Electrical conductance studies: LiF-LiI

Investigations critically re-examined			
Ref.	LiI mol %	Temp. range (T)	Comments
89 <sup>a</sup>	83.5, 100	726-821	Quartz capillary cell; Pt electrodes; freq. range: 5000-45,000 Hz; calibration: molten salts.
82	0-100	758-1273	Pt electrode; freq. range: 50,000 Hz.
Deviations from previous NSRDS recommendations [1, pp. 3, 19]			
Ref.	LiI mol %	Min. departure	Max. departure
82	100	0.29% (875 K)	0.40% (760 K)
82	0	0.03% (1260 K)	-2.56% (1150 K)

<sup>a</sup>Reference [89] is the NSRDS data base for the specific conductance of molten lithium iodide.

TABLE 71. LiF-LiI: Specific conductance ( $\text{ohm}^{-1}\text{cm}^{-1}$ )

T	Mol percent LiI						
	100	75	63	50	37	25	0
760	4.005	2.467	2.033	1.863	1.667	1.651	4.871
780	4.103	2.559	2.107	1.959	1.775	1.763	5.090
800	4.198	2.647	2.178	2.054	1.884	1.876	5.305
820	4.292	2.733	2.247	2.148	1.993	1.990	5.519
840	4.379	2.817	2.315	2.240	2.103	2.103	5.724
860	4.463	2.900	2.380	2.332	2.212	2.217	5.930
880	4.543	2.979	2.444	2.422	2.322	2.331	6.132
900	4.618	3.057	2.505	2.511	2.430	2.447	6.326
920	4.692	3.132	2.565	2.598	2.539	2.560	6.520
940	4.760	3.205	2.623	2.683	2.646	2.673	6.710
960	4.827	3.275	2.679	2.768	2.753	2.787	6.896
980	4.889	3.343	2.733	2.850	2.859	2.898	7.073
1000	4.950	3.409	2.785	2.931	2.963	3.009	7.254
1020	5.007	3.473	2.836	3.010	3.066	3.118	7.421
1040	5.059	3.533	2.884	3.087	3.169	3.227	7.590
1060	5.109	3.593	2.932	3.163	3.269	3.335	7.755
1080	5.157	3.649	2.975	3.237	3.369	3.441	7.917
1100	5.201	3.705	3.019	3.307	3.466	3.545	8.071
1120	5.244	3.757	3.061	3.379	3.562	3.648	8.218
1140	5.285	3.808	3.100	3.447	3.657	3.751	8.368
1160	5.322	3.855	3.138	3.511	3.749	3.851	8.510
1180	5.354	3.902	3.173	3.577	3.841	3.949	8.645
1200	5.387	3.945	3.210	3.639	3.930	4.045	8.784
1220	5.418	3.988	3.244	3.700	4.019	4.141	8.914
1240	5.445	4.030	3.274	4.103	4.103	4.235	9.042
1260	5.472	4.070	3.307	4.189	4.189	4.324	9.164

TABLE 71. LiF-LiI: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )—Continued

Temperature-dependent equations $\kappa = a + bT + cT^2 + dT^3 + eT^4$						
Mol % LiI	-a	$b \cdot 10^3$	$c \cdot 10^6$	$-d \cdot 10^9$	$e \cdot 10^{12}$	Standard error of estimate
100	3.62727	16.0374	-9.24434	-1.78348		0.018%
75	2.97832	9.90818	-3.89050	-0.369061		0.027%
63	0.929985	2.02887	6.15144	6.08011	1.62537	0.025%
50	2.43833	6.03857	0.0362856	0.706150		0.027%
37	-0.667306	-7.30341	18.6039	11.31381	2.30892	0.018%
25	0.0814219	-4.23728	13.4613	7.37387	1.23944	0.020%
0	6.30288	18.1177	-4.28362	0.281087		0.028%

These values are based on the work of Smirnov, Khokhlov, Stepanov, and Shumov (classical ac technique) [82]. These authors reported equivalent conductance. The data were converted to specific conductance using the density equations reported in the same paper.

TABLE 72. Density studies: LiF-LiI

Investigations critically re-examined			
Ref.	LiI mol %	Temp. range (T)	Comments
82	0-100	785-1273	Pt sphere; calibration: molten $\text{KNO}_3$ .
Deviations from previous NSRDS recommendations [1, pp. 3, 19]			
Ref.	LiI mol %	Min. departure	Max. departure
82	100	0.48% (760 K)	0.49% (880 K)
82	0	0.01% (1210 K)	0.27% (1270 K)

TABLE 73. LiF-LiI: Density ( $\text{g cm}^{-3}$ )

T	Mol percent LiI				
	100	75	50	25	0
760	3.108	2.925	2.745	2.486	1.951
780	3.089	2.910	2.731	2.474	1.943
800	3.071	2.894	2.717	2.463	1.935
820	3.053	2.878	2.703	2.451	1.927
840	3.034	2.862	2.689	2.439	1.918
860	3.016	2.846	2.675	2.427	1.910
880	2.997	2.830	2.661	2.415	1.902
900	2.979	2.814	2.647	2.404	1.893
920	2.961	2.799	2.633	2.392	1.885
940	2.942	2.783	2.619	2.380	1.877
960	2.924	2.767	2.605	2.369	1.869
980	2.905	2.751	2.591	2.357	1.860
1000	2.887	2.735	2.577	2.345	1.852
1020	2.869	2.719	2.563	2.333	1.844
1040	2.850	2.703	2.549	2.321	1.835
1060	2.832	2.687	2.535	2.310	1.827
1080	2.813	2.671	2.521	2.298	1.819
1100	2.795	2.656	2.507	2.286	1.811
1120	2.777	2.640	2.493	2.274	1.802
1140	2.758	2.624	2.479	2.263	1.794
1160	2.740	2.608	2.465	2.251	1.786
1180	2.721	2.592	2.451	2.239	1.777
1200	2.703	2.567	2.437	2.227	1.769
1220	2.685	2.560	2.423	2.216	1.761
1240	2.666	2.544	2.409	2.204	1.753
1260	2.648	2.529	2.395	2.192	1.744

Temperature-dependent equations

$$\rho = a - bT$$

Mol % LiI	a	$b \cdot 10^3$	Standard deviation
0	2.266	0.414	0.002
25	2.933	0.588	0.004
50	3.275	0.698	0.005
75	3.529	0.794	0.005
100	3.807	0.920	0.005

These values are based on the work of Smirnov, Khokhlov, Stepanov and Shumov (modified maximum bubble pressure method) [82]. The following equation, with concentration,  $C$ , in mole percent LiI and temperature in K, has been derived from the preceding data:  $\rho = a + bC + cT + dC^2 + eC^3 + fTC + gT^2$ , where,  $a = 2.26901$ ,  $b \cdot 10^3 = 3.35030$ ,  $c \cdot 10^4 = -4.15396$ ,  $d \cdot 10^4 = -3.08415$ ,  $e \cdot 10^6 = -1.35819$ ,  $f \cdot 10^8 = -6.7312$ ,  $g \cdot 10^8 = 1.82021$ , with a maximum departure of 0.49% at 1258 K and 75 mol % LiI, and a standard error of estimate of 0.006. This equation may be used to calculate the density of LiF-LiI melts at any concentration in the temperature range 758-1273 K.

TABLE 74. Surface tension studies: LiF-LiI

Investigations critically re-examined			
Ref.	LiI mol %	Temp. range (T)	Comments
79	0-100	870-1240	Molybdenum crucible; calibration: molten NaCl.
Deviations from previous NSRDS recommendations [2, p. 55]			
Ref.	LiI mol %	Min. departure	Max. departure
79	0	1.70% (1170 K)	1.76% (1240 K)

TABLE 75. LiF-LiI: Surface tension (dyn cm<sup>-1</sup>)

T	Mol percent LiI				
	100	75	50	25	0
870	91.5				
880	91.0				
890	90.4	109.2			
900	89.9	108.6			
910	89.3	107.9			
920	88.7	107.3			
930	88.1	106.7			
940	87.6	106.1			
950	87.0	105.5			
960	86.5	104.9	132.8		
970	85.9	104.3	132.0		
980	85.3	103.6	131.3		
990	84.8	103.0	130.5		
1000	84.2	102.4	129.8		
1010	83.6	101.8	129.1		
1020	83.1	101.2	128.3		
1030	82.5	100.5	127.5		
1040	81.9	99.9	126.8		
1050	81.4	99.3	126.1		
1060	80.8	98.7	125.3		
1070	80.2	98.1	124.5		
1080	79.7	97.5	123.8	168.0	
1090	79.1	96.8	123.1	167.1	
1100	78.5	96.2	122.3	166.3	241.7
1110			121.6	165.4	240.7
1120			120.8	164.5	239.8
1130			120.1	163.6	238.6
1140			119.3	162.7	237.8
1150			118.6	161.8	236.8
1160			117.8	160.9	235.8
1170			117.1	160.1	234.8
1180				159.2	233.9
1190				158.3	232.9
1200				157.4	231.9
1210				156.5	230.9
1220				155.7	229.9
1230					228.9
1240					227.9

Temperature-dependent equations

$$\gamma = a - bT$$

Mol % LiI	a	b
0	350.2	0.0986
25	263.5	0.0884
50	204.7	0.0749
75	164.1	0.0617
100	140.7	0.0565

These values are based on the work of Smirnov and Stepanov (maximum bubble pressure method [79]). The data were reported in equation form and no error estimate was given.

## 5.4. Chloride-Bromide Systems

## AgCl-AgBr

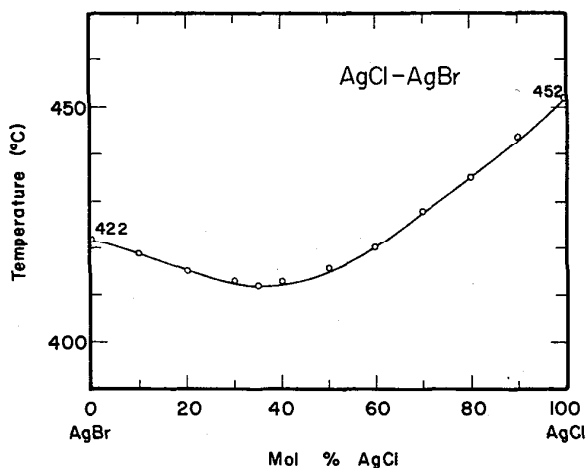


FIGURE 14. Temperature-composition phase diagram for AgCl-AgBr.

K. Monkemeyer, Neues Jahrb. Mineral., Geol., Palantol., Beil.Band, 22, 1, (1906).

## Melt Preparation and Purification

Boardman et al. [12] used salts either of analytical grade purity or obtained from reagents of that purity and recrystallized. They prepared silver bromide from the nitrate and hydrobromic acid. Mixtures were prepared by melting weighed quantities of fused silver chloride and silver bromide together.

Harrap and Heymann [15] precipitated the silver halides from aqueous solutions of A. R.  $\text{AgNO}_3$  with the corresponding hydrogen halide. The salts were dried by evaporating the solution to dryness in the dark in the presence of excess acid.

Brooks and Paul [67, 70] used 99.8% B. D. H. AgCl dried by heating under vacuum for three days at 150 °C, followed

by treatment with a stream of freshly prepared dry HCl gas while gradually raising the temperature to the melting point. Similarly, 99.9% Research Inorganic Chemical Corporation AgBr was dried by heating under vacuum for three days at 200 °C, followed by treatment with dry, freshly prepared HBr for two hours while raising the temperature to the melting point. Dry nitrogen was bubbled through the melt for two hours to remove all traces of HBr.

TABLE 76. Electrical conductance studies: AgCl-AgBr

Investigations critically re-examined			
Ref.	AgBr mol %	Temp. range (T)	Comments
8	0,30,50,70,100	773	Cell material: silica and quartz U-tubes; Pt electrodes; calibration: 1N KCl solution.
15 <sup>a</sup>	0-100	713-873	Pt electrodes; freq. range: $\approx 3000$ Hz; calibration: 1N KCl solution.

## Deviations from previous NSRDS recommendations [1, pp. 10, 16]

Ref.	AgBr mol %	Min. departure	Max. departure
8	100	-3.3% (773 K)	
8	0	-8.5% (773 K)	
15	0	-2.4% (978 K)	-2.6% (873 K)

<sup>a</sup>The mixtures in reference [15] were not heated above 600 °C inasmuch as above that temperature the melts were observed to decompose with liberation of bromine. The data reported were taken from smoothed curves drawn through the experimental points. The deviation of these points from the conductivity curves was never greater than 0.05%.



TABLE 77. AgCl-AgBr: Specific conductance ( $\text{ohm}^{-1} \text{cm}^{-1}$ )

<i>T</i>	Mol percent AgBr					
	100	80	60	40	20	0
720	2.89	2.99	3.15	3.32	3.50	
730	2.92	3.02	3.18	3.36	3.54	3.73
740	2.95	3.06	3.22	3.39	3.58	3.77
750	2.97	3.09	3.25	3.42	3.62	3.81
760	2.99	3.13	3.28	3.46	3.66	3.85
770	3.02	3.16	3.30	3.49	3.70	3.89
780	3.04	3.18	3.33	3.52	3.73	3.92
790	3.06	3.21	3.36	3.55	3.76	3.96
800	3.08	3.24	3.38	3.58	3.80	3.99
810	3.10	3.26	3.41	3.61	3.83	4.02
820	3.12	3.28	3.43	3.63	3.86	4.06
830	3.14	3.30	3.46	3.66	3.88	4.09
840	3.16	3.32	3.47	3.69	3.91	4.12
850	3.17	3.34	3.50	3.71	3.93	4.15
860	3.19	3.35	3.52	3.73	3.96	4.18
870	3.21	3.37	3.54	3.76	3.98	4.21
880						4.24
890						4.26
900						4.29
910						4.31
920						4.34
930						4.36
940						4.38
950						4.41
960						4.43
970						4.45

Temperature-dependent equations

$$\kappa = a + bT + cT^2$$

Mol % AgBr	$-a$	$b \cdot 10^2$	$-c \cdot 10^6$	Standard error of estimate
0	1.4332	1.0160	4.2248	0.15%
20	3.1339	1.4217	6.9438	0.15%
40	1.3888	0.9546	4.1725	0.18%
60	1.5896	0.9896	4.5987	0.17%
80	4.2603	1.6284	8.6401	0.32%
100	1.2864	0.8886	4.2800	0.10%

The values in this table are based on the work of Harrap and Heymann (classical ac technique) [15].

TABLE 78. Density studies: AgCl-AgBr

Investigations critically re-examined			
Ref.	AgBr mol %	Temp. range (T)	Comments
12 <sup>a</sup>	0,22.7, 40.3, 65.8 100,	693-903	Silica glass dilatometer; calibration: molten AgNO <sub>3</sub> .
67, 70	50,100	760-1037	Pt bob, Pt suspension wire; calibration: water.
Deviations from previous NSRDS recommendations [1, pp. 10, 16]			
Ref.	AgBr mol %	Min. departure	Max. departure
12	0	-0.82% (760 K)	-1.0% (900 K)
67,70	100	0.00% (930 K)	0.06% (720 K)

<sup>a</sup>Boardman et al. [12] applied corrections for the shape of the meniscus, buoyancy and the expansion of the silica dilatometer.

TABLE 79. AgCl-AgBr: Density (g cm<sup>-3</sup>)

T	Mol percent AgBr				
	100	65.8	40.3	22.7	0
700		5.375	5.200		
710		5.365	5.189		
720	5.561	5.354	5.178	5.040	
730	5.551	5.343	5.166	5.030	
740	5.540	5.333	5.155	5.019	
750	5.530	5.322	5.144	5.008	
760	5.520	5.311	5.133	4.997	4.804
770	5.509	5.300	5.122	4.986	4.795
780	5.499	5.290	5.110	4.976	4.786
790	5.488	5.279	5.099	4.965	4.776
800	5.478	5.268	5.088	4.954	4.767
810	5.468	5.258	5.077	4.943	4.757
820	5.457	5.247	5.066	4.932	4.748
830	5.447	5.236	5.054	4.922	4.739
840	5.436	5.226	5.042	4.911	4.729
850	5.426	5.215	5.032	4.900	4.720
860	5.416		5.021		4.710
870	5.405				4.701
880					4.692
890					4.682
900					4.673

Temperature-dependent equations

$$\rho = a - bT$$

Mol % AgBr	a	b·10 <sup>3</sup>
0	5.519	0.94
22.7	5.818	1.08
40.3	5.984	1.12
65.8	6.124	1.07
100	6.310	1.04

The values in this table are based on the work of Boardman, Dorman and Heymann (dilatometric method) [12]. These authors estimated the maximum error to be  $\pm 0.15\%$ . The following equation, with concentration,  $C$ , in mole percent AgCl and temperature in K, has been derived from the preceding data:  $\rho = a + bT + cC^2 + dTC + eTC^2$ , where  $a = 6.32998$ ,  $b \cdot 10^3 = -1.06497$ ,  $c \cdot 10^5 = -1.44515$ ,  $d \cdot 10^5 = -1.44609$ ,  $e \cdot 10^9 = 9.21738$ , with a maximum percent departure of 0.14% at 863.2 K and 59.7 mol % AgCl, and a standard error of estimate of 0.002. This equation may be used to calculate the density of AgCl-AgBr melts at any concentration in the temperature range 693-903 K.

TABLE 80. Viscosity studies: AgCl-AgBr

Investigations critically re-examined			
Ref.	AgBr mol %	Temp. range (T)	Comments
15 <sup>a</sup>	0-100	713-873	Cell material: B.T.H.-C14 glass; calibration: molten KNO <sub>3</sub> .
37	0-100	773	As for [15], and see also [11].

<sup>a</sup>Reference [15] is the NSRDS reference data base for the viscosity of pure molten AgCl and of pure molten AgBr. The data reported by the authors were obtained from smoothed curves through the experimental points. The deviation of these points from the curves was never greater than 1.5%.

TABLE 81. AgCl-AgBr: Viscosity (cp)

T	Mol percent AgBr					
	100.0	80.0	60.0	40.0	26.8	0.0
720	3.30	3.05	2.91	2.70	2.53	
730	3.20	2.96	2.82	2.62	2.47	2.29
740	3.11	2.87	2.74	2.55	2.41	2.24
750	3.03	2.78	2.66	2.47	2.35	2.19
760	2.94	2.70	2.58	2.40	2.29	2.14
770	2.86	2.63	2.51	2.33	2.23	2.09
780	2.79	2.55	2.44	2.27	2.18	2.05
790	2.72	2.48	2.37	2.20	2.12	2.00
800	2.65	2.42	2.31	2.14	2.07	1.96
810	2.58	2.36	2.25	2.08	2.02	1.91
820	2.52	2.30	2.19	2.02	1.97	1.87
830	2.47	2.25	2.14	1.96	1.92	1.83
840	2.42	2.21	2.10	1.90	1.88	1.79
850	2.37	2.17	2.05	1.85	1.84	1.75
860	2.33	2.13	2.02	1.80	1.79	1.71
870	2.29	2.10	1.99	1.75	1.76	1.67
880						1.64
890						1.61
900						1.58
910						1.55
920						1.52
930						1.49
940						1.47
950						1.45
960						1.43
970						1.41

Temperature-dependent equations

$$\eta = a + bT + cT^2 + dT^3$$

Mol % AgBr	a	b·10 <sup>3</sup>	c·10 <sup>5</sup>	d·10 <sup>8</sup>	Standard error of estimate
0	3.1508	8.7420	-2.1890	1.1367	0.46%
26.8	5.9550	2.6085	-1.8307	1.1219	0.55%
40	7.0068	2.1679	-2.0421	1.2629	0.13%
60	9.3546	1.4645	-2.9122	2.0346	0.27%
80	9.6253	3.3292	-3.4298	2.3594	0.30%
100	15.4159	-18.7388	-0.4743	1.0270	0.31%

These values are based on the work of Harrap and Heymann (capillary method) [15].

TABLE 82. Surface tension studies: AgCl-AgBr

Investigations critically re-examined			
Ref.	AgBr mol %	Temp. range (T)	Comments
76 <sup>a</sup>	0-100 (g)	773,883	Cell material: capillary of B.T.H.-C46 glass; melt contained in a tube of B.T.H.-Cl4 glass; calibration: water;

<sup>a</sup>Boardman, Palmer and Heymann [76] calibrated their apparatus before and after each experiment and found the calibration reproducible to within 0.3%. The maximum error was estimated to be  $\pm 1.0\%$ .

TABLE 83. AgCl-AgBr: Surface tension (dyn cm<sup>-1</sup>)

Mol percent AgBr	773 K	883 K
0	176.0	171.0
10	172.9	168.3
20	169.6	165.5
30	166.6	162.9
40	163.8	160.4
50	161.0	158.1
60	158.7	156.0
70	156.5	154.0
80	154.6	152.4
90	153.2	151.2
100	152.1	150.2

These values have been interpolated to four significant figures from the graphical presentation of Boardman, Palmer and Heymann (maximum bubble pressure method) [76].

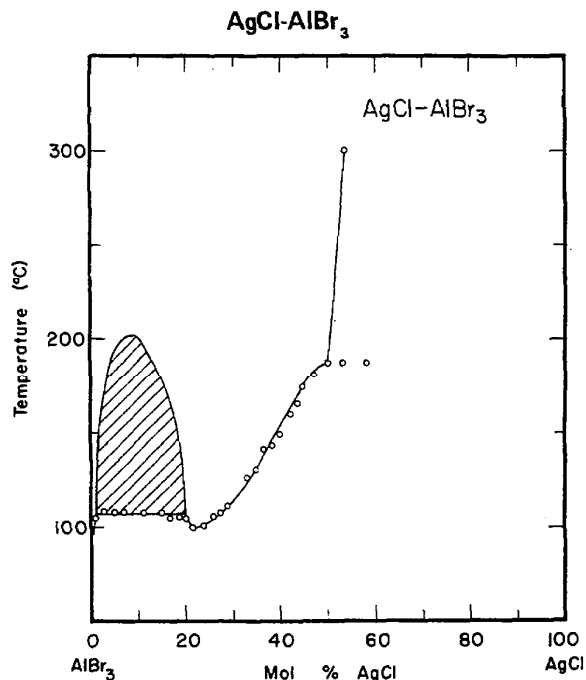


FIGURE 15. Temperature-composition phase diagram for AgCl-AIBr<sub>3</sub>.

V. A. Plotnikov and U. I. Shartsman, Zap. Inst. Khim., Akad. Nauk SSSR, 4, 222 (1937); Zh. Fiz.-Khim. 12, 120 (1938).

J. Phys. Chem. Ref. Data, Vol. 8, No. 1, 1979

### Melt Preparation and Purification

Reference [35] contains no information on melt preparation.

TABLE 84. Electrical conductance studies: AgCl-AIBr<sub>3</sub>

Investigations critically re-examined		
Ref.	AIBr <sub>3</sub> mol %	Temp. range
35	73.80	373-443

TABLE 85. AgCl-AIBr<sub>3</sub>: Specific conductance (ohm<sup>-1</sup> cm<sup>-1</sup>)

T	Mol % AIBr <sub>3</sub> 73.8
373.2	0.0107
378.2	0.0116
383.2	0.0121
388.2	0.0136
393.2	0.0148
398.2	0.0161
403.2	0.0168
408.2	0.0178
413.2	0.0190
418.2	0.0214
423.2	0.0242
438.2	0.0296
443.2	0.0322

These values are based on the work of Mezhenii (classical ac technique) [35].