FREZCHEM2
A Chemical Thermodynamic Model for Electrolyte Solutions at Subzero Temperatures
Mikhail V. Mironenko, Steven A. Grant, Giles M. Marion, and Ronald E. Farren
October 1997

- number of independent components
H2O: 1
- the name of the independent component, its charge and its code (the codes in this model are the same as
Na+: 1
Cl-: 1
Ca2+: 2
Mg2+: 2

5. number of cations
- number of cations
Ca2+: 1
Mg2+: 1
Na+: 1
Cl-: 1

6. number of anions
- number of anions
Ca2+: 1
Mg2+: 1
Na+: 1
Cl-: 1

14. number of all phases
Na+: 1
Ca2+: 1
Mg2+: 1
Cl-: 1

Call Pitzer
Call Gauss-Jordan

Phase removal
Phase addition (call Simplex)

Print results
Abstract: This report documents a Fortran version of a chemical thermodynamic model for aqueous electrolyte solutions at subzero temperatures, FREZCHEM2, which is a further development of the FREZCHEM model. The model uses thermodynamic data of Spencer–Møller–Weare that permit the calculation of chemical equilibria in the Na–K–Ca–Mg–Cl–SO$_4$–H$_2$O system between -60 and 25°C at atmospheric pressure. It applies the Gibbs energy minimization method for chemical equilibrium computation combined with Pitzer equations for activity coefficients and water activity calculation. The model includes both the freezing (melting) reaction pathway at fixed water amount and the evaporation (dilution) pathway at fixed temperature. The FREZCHEM2 model can be extended with respect to independent components, electrolyte species, and solids, and if corresponding thermodynamic data are available, the model may be used to compute chemical equilibria in any systems that include aqueous-solution and/or one-component solid phases.
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Prepared for
U.S. ARMY RESEARCH, DEVELOPMENT, AND STANDARDIZATION GROUP (UK)
OFFICE OF THE CHIEF OF ENGINEERS

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PREFACE

This report was prepared by Dr. Mikhail V. Mironenko, Senior Researcher of the Vernadsky Institute of Geochemistry and Analytical Chemistry of the Russian Academy of Sciences, and Dr. Steven A. Grant, Dr. Giles M. Marion, and Dr. Ronald E. Farren, Research Physical Scientists of the Geochemical Sciences Branch, U.S. Army Cold Regions Research and Engineering Laboratory.

Funding was provided by the European Research Office of the U.S. Army, Project WK2Q6C-7411-EN09. Funding was also provided by U.S. Army Projects AT24-SC-F02, Chemical Processes in Frozen Soil, and BT25-EC-B03, Air–Snow–Ice–Soil Contaminant Interactions in Cold Regions.

The authors thank Dr. Virgil J. Lunardini of USACRREL and Dr. Jerry P. Greenberg of the University of California at San Diego for reviewing an earlier draft of this manuscript.

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CONTENTS
Preface ................................................................................................................................................... ii
Introduction ........................................................................................................................................ 1
Mathematical algorithm .................................................................................................................... 1
   Local minimum computation ........................................................................................................ 1
   Search for the equilibrium phase assemblage .............................................................................. 4
   Special steps .................................................................................................................................. 4
FREZCHEM2 program ....................................................................................................................... 4
   Data files ........................................................................................................................................ 5
   Program input and output ............................................................................................................. 5
Literature cited ..................................................................................................................................... 6
Appendix A: Fortran listing of the FREZCHEM2 program ................................................................. 11
Appendix B: Data files for program FREZCHEM2 ......................................................................... 39
Abstract .............................................................................................................................................. 41

ILLUSTRATION
Figure
   1. Flowchart of the FREZCHEM2 model ...................................................................................... 5

TABLES
Table
   1. FREZCHEM2 model input for freezing seawater from 0° down to −40°C with a
      2°C decrement ............................................................................................................................ 6
   2. FREZCHEM2 model output for freezing seawater at −45°C and at −55°C ......................... 7
   3. FREZCHEM2 model output for evaporation of seawater at 0°C ........................................... 8
   4. Temperatures of first appearance of solid phases on chilling seawater ............................ 8
FREZCHEM2
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MIKHAIL V. MIRONENKO, STEVEN A. GRANT, GILES M. MARION, AND RONALD E. FARREN

INTRODUCTION

The FREZCHEM model was developed by Marion and Grant (1994) to calculate chemical equilibria among aqueous electrolyte solutions, ice, and salts. The model applies the Pitzer equations for calculation of aqueous species and water activities. To find chemical equilibrium, this program solves sequentially a set of nonlinear equations that includes both solid-phase deposition and ion-pair formation using an individual subroutine for every reaction. FREZCHEM uses data on constants of chemical reactions and Pitzer equation parameters published by Spencer et al. (1990). The results of modeling show good agreement both with experimental data and with the results of the Spencer-Moller-Weare model. However, the FREZCHEM model has some limitations. One is convergence problems at high ionic strengths (>15 molal) and at junctions, where new phases begin to precipitate. Another is that addition of any new substance into this model requires changes not only in data but also in the program code.

The objective of this report is the further development of the chemical thermodynamic model FREZCHEM to make it more reliable, universal, and flexible. The point calculation reliability was improved by applying the Gibbs energy minimization approach to computing equilibrium. The thermodynamic information needed for computations is separated from the calculating routines. That allows components to be added to the system without code changes and the program code to be applied for other chemical systems. It should be noted that the Pitzer approach describes most interactions in aqueous solution as electrostatic and only explicitly recognizes a few chemical interactions, such as ion-pair formation. This is why the system under consideration is very simple from the viewpoint of chemical interactions, but it is very complex from the viewpoint of the influence of activity coefficients on the behavior of the Gibbs energy function.

MATHEMATICAL ALGORITHM

The system under investigation consists of the following components: 1) solid salts of fixed chemical composition and pure ice (so-called one-component phases), and 2) aqueous solutions consisting of water and dissolved electrolytes. The applied algorithms of chemical equilibria computation will be described in terms of these components.

The equilibrium composition of the system at constant $T$, $P$, and specified bulk composition may be found by minimizing the Gibbs energy function of the system under balance restrictions.

Local minimum computation

Local minimum is considered as an equilibrium composition of the system, in which all existing phases are specified before computation. The Gibbs energy function of the system that contains $M$ solids and aqueous solution (water and $J$ species) is as follows:

$$g = \frac{G}{RT} = \sum_{k=1}^{M} \mu_k n_k + \mu_w n_w + \sum_{j=1}^{J} \mu_j n_j$$

where $G =$ free energy of the system,

$n =$ the molal quantity of components,
\[ \mu_j = \text{the chemical potential of species } j, \]
\[ \mu_w = \text{the chemical potential of water}, \]
\[ \mu_k^0 = \text{the standard chemical potential of a one-component solid-phase } k, \]
\[ R = \text{the universal gas constant}. \]

The chemical potential of aqueous solution species \( j \) in terms of molality is defined by

\[ \mu_j = \mu_j^0 + \ln a_j = \mu_j^0 + \ln (m_j \gamma_j) \]

where \( \mu_j^0 \) is the standard chemical potential,

\[ m_j = \frac{n_j}{n_w} \times 55.51 \]

is the moles of the \( j \)th species per 1 kg of water (molality), and \( \gamma \) is an activity coefficient.

The chemical potential of water may be written as

\[ \mu_w = \mu_w^0 + \ln a_w \]

where water activity \( a_w \), according to Pitzer (1987), is defined through the osmotic coefficient of the solution \( \phi \) and molalities of species by

\[ \ln a_w = -\phi \frac{W}{1000} \left( \sum_j m_j \right) \]

where \( W \) is the molecular weight of water (18.0153).

Accordingly, the free energy function of the system is as follows:

\[ g(\vec{n}) = \sum_{k=1}^{M} \mu_k^0 n_k + n_w (\mu_w^0 - \phi \frac{\sum n_j}{n_w}) \]
\[ + \sum_{j=1}^{J} n_j \left[ \mu_j^0 + \ln \left( \frac{n_j \times 55.51}{n_w \gamma_j} \right) \right]. \] (1)

Mass balance constraints, including the electroneutrality equation if necessary, may be written as a system of linear equations:

\[ \sum_{j=1}^{J} v_{ij} n_j = b_i, \quad i = 1, P \] (2)

where \( P \) is the number of independent chemical components in the system, and \( v_{ij} \) is the number of moles (stoichiometric units) of independent component \( i \) in one mole of component \( j \). \( b_i \) represents the number of moles of independent component \( i \) in the system. For the electroneutrality equation \( b_i = 0 \) and \( v_{ij} = z_j \), where \( z_j \) is the charge of the \( j \)th component. In matrix notation, eq 2 may be written as

\[ N \vec{n} = \vec{b} \]

where \( N \) is the stoichiometric matrix, \( \vec{n} \) is the vector of numbers of moles of species, and \( \vec{b} \) is the vector of bulk chemical composition of the system.

It is convenient to solve the system of linear equations (eq 2) with respect to \( P \) components, including \( M (M \leq P) \) solids,

\[ n_k = B_k - \sum_{j=1}^{J} a_{kj} n_j \quad k = 1, M \] (2a)
\[ f_i = B_i - \sum_{j=1}^{J} a_{ij} n_j = 0 \quad i = M + 1, P \] (2b)

and in this way to switch to new independent components. In such a manner the stoichiometry of other \( J + 1 - P \) components (vectors \( \vec{a}_j \)) and the matter balance \( \vec{B} \) are now defined through these independent components. This operation allows the number of active constraints to be reduced up to \( P - M \). The thermodynamic meaning of this lies in the fact that the chemical potential of a one-component solid phase is equal to the standard Gibbs energy of formation and does not depend on its amount, until this phase is present. This is why the system can be considered to be open with respect to this component.

It is obvious that

\[ n_w > 0 \text{ and } n_j > 0. \] (3)

Minimization of the function in eq 1 under the constraints of eq 2 and eq 3 can be replaced by a search of the extremum of the Lagrangian function, which may be written as

\[ \Phi(\vec{n}, \vec{\lambda}) = g(\vec{n}) + \sum_{k=1}^{M} \mu_k^0 (B_k - \sum_{j=1}^{J+1} a_{kj} n_j) \]
\[ + \sum_{i=m+1}^{P} \lambda_i (B_i - \sum_{j=1}^{J+1} a_{ij} n_j) \]

where \( \lambda \) is a Lagrangian multiplier. It can be shown (Karpov et al. 1976) that \( \lambda \) is the chemical potential of the corresponding independent component of the system. In particular for solids, \( \lambda_k = \mu_k^0 \).
The conditions of extremum of the Lagrangian function are found where all first partial derivatives with respect to components and to Lagrangian multipliers are equal to zero. This gives

$$\frac{\partial \Phi}{\partial n_j} = (\mu_j^0 + \ln 55.5) + \ln\left(\frac{n_j}{n_w} - \gamma_j\right)$$

$$- \sum_{k=1}^{M} \mu_{k} \alpha_{kj} - \sum_{i=M+1}^{P} \lambda_i \alpha_{ij} = 0 \quad (4a)$$

$$\frac{\partial \Phi}{\partial n_w} = -\phi \frac{n_j}{n_w} - \sum_{k=1}^{M} \mu_{k} a_{kw}$$

$$- \sum_{i=M+1}^{P} \lambda_i a_{iw} = 0 \quad (4b)$$

$$\frac{\partial \Phi}{\partial \lambda_k} = B_j - \sum_{j=1}^{I} a_{ij} n_j - a_{iw} n_w = 0. \quad (4c)$$

There are different approaches to searching the Lagrangian function extremum. One of them is the algorithm developed by White (1958, 1967) for homogeneous gas systems, which has been further developed for heterogeneous multiphase systems by Karpov (1976). This algorithm was applied by the senior author of this report for computation of a wide range of chemical equilibria (Mironenko 1991, 1992) and is build into the DiaNIK system (Khodakovsky 1992). The idea of the method, as applied to the system under consideration, is as follows. Equation 4a may be solved with respect to $n_j$:

$$n_j = \frac{n_w}{\gamma_j} \exp\left(\sum_{k=1}^{M} \mu_{k} \alpha_{kj} + \sum_{i=M+1}^{P} \lambda_i \alpha_{ij} - \mu_j^0\right). \quad (5)$$

Substitution of these terms into eq 4b and c gives the system of $P - M + 1$ equations, which may be solved by Newton’s method for $\lambda$ and $n_w$. The advantages of this approach are a fast rate of computation, due to a small amount of variables (their amount does not depend on the number of species), and the lack of necessity to undertake special steps to calculate species at very low concentrations or to correct negative values of mass for species during iterations. Unfortunately, attempts to apply this approach to brine systems in combination with Pitzer’s routine have demonstrated that the algorithm is not tolerant of oscillations of activity coefficient values, provided by Pitzer’s routine at every iteration. Because of this it was very difficult to reach the required precision of solution (0.1%), even when special steps were undertaken.

Another approach is to solve the whole system of $P - M + f + 1$ equations (eq 4 a, b, c) iteratively by Newton’s method for $n_j$, $n_w$, and $\lambda_k$. This algorithm has been described in detail by Harvie et al. (1987). It has been successfully applied by Spencer et al. (1990) for strong electrolyte solution modeling, but a working version of the program has not been published. This algorithm also was applied by Mironenko (1983) for modeling fluid-rock interactions during hydrothermal uranium ore formation.

The second partial derivatives of the Lagrangian function are equal to

$$\frac{\partial^2 \Phi}{\partial n_j \partial n_j} = \begin{cases} \frac{1}{n_j}, & \text{if } j = j_1 \\ 0, & \text{if } j \neq j_1 \end{cases}$$

$$\frac{\partial^2 \Phi}{\partial n_j \partial n_w} = -\phi \frac{1}{n_w}$$

$$\frac{\partial^2 \Phi}{\partial n_w \partial \lambda_i} = \phi \frac{1}{n_w}$$

$$\frac{\partial^2 \Phi}{\partial n_w \partial \lambda_{i1}} = \sum_{j=1}^{I} \phi$$

$$\frac{\partial^2 \Phi}{\partial \lambda_i \partial \lambda_k} = -\alpha_{ij}$$

$$\frac{\partial^2 \Phi}{\partial \lambda_i \partial n_j} = -\alpha_{ij} n_j$$

$$\frac{\partial^2 \Phi}{\partial \lambda_i \partial n_w} = -\alpha_{iw} n_w$$

$$\frac{\partial^2 \Phi}{\partial \lambda_{i1} \partial \lambda_{j1}} = 0.$$
Search for the equilibrium phase assemblage

Solids

If a molal quantity of solid calculated using eq 2a was negative, this solid phase was considered as completely dissolved, and a new local equilibrium without this solid was computed. Then a search of new solid phases from the list of possible solids to be included into the system is undertaken. The criterion for the inclusion of phase K is as follows:

\[ \sum_{k=1}^{M} \mu_k a_{ik} + \sum_{i=M+1}^{P} \lambda_i a_{ik} - \mu_k^0 < 0. \]  

The thermodynamic meaning of this expression is that the free energy of chemical reaction of a given solid substance formed from independent components of the system is negative, and therefore this solid is thermodynamically stable. If the condition (eq 6) asserts, this solid replaces one of the independent components of the system with which it is linearly dependent. Then the system of linear equations (eq 2a,b) is solved with respect to this new independent component. By this means the chemical composition of all components of the system will be expressed in terms of this and other independent components. This procedure is largely achieved by applying the Simplex routine. (Simplex is a classic finite iteration method of linear programming [Korn and Korn 1963].) Addition of each solid phase reduces the number of active linear restrictions by one. Calculations are continued until, in the list of possible phases, there is no phase that meets the condition in eq 6.

Aqueous solution

Aqueous solution is considered absent in the system when the number of active balance restrictions \((P - M)\) is less than or equal to one and the amount of water is less than 0.001 moles.

Special steps

Usually, the approximate phase composition of a system may be determined at the first steps of calculation using the Simplex routine. Then the exact equilibrium composition may be computed using Newton’s method for local equilibria determination and Simplex methods for addition or substitution of solids. Due to the very high non-ideality of brines, this technique collapsed, and some changes in the logical pattern of calculation were made:

1. At first, the system is considered homogeneous (no solids), then the solid-phase assemblage is calculated, not simultaneously during one application of the Simplex routine, but sequentially. Another phase is added after local equilibrium with previously added phases is achieved.

2. After the appearance of a new solid phase and before applying Newton’s method, the current species concentrations have to be recalculated to be in better agreement with values of independent component chemical potentials. The relation between concentration of species and values of chemical potentials of independent components is expressed by eq 5 and can be also treated in terms of the free energy of the chemical reaction of species formation from independent components of the system.

3. Because of particularities of Pitzer’s model, to prevent wide fluctuations during solution of the system of equations \(4ab,c\) by Newton’s method, we have to smooth changes of activity coefficient and osmotic coefficient values, which are calculated at each iteration by Pitzer’s routine. We use average values obtained at the current and previous iterations.

4. At every iteration a new approximation to the solution is provided by inversion of the Hessian matrix: \(y_i^{(k+1)} = y_i^{(k)} + \Delta_i / \xi\). For a homogeneous system the value of \(\xi\) is equal to 1 and it increases by 0.5 with every new solid that precipitates.

FREZCHEM2 PROGRAM

A listing of the FREZCHEM2 Fortran program is in Appendix A. FREZCHEM2 consists of a main program called READWRITE and seven subroutines.

The READWRITE program reads input data from the file INPUT, according to these data forms independent components of the system, and reads the temperature interval and temperature step for freezing, or the water content interval and water decrement at a given temperature for the evaporation scenario. It calculates chemical potentials of the components as functions of temperature, calls various subroutines, and writes results of the chemical equilibria computation into the file RESULT.

Subroutine CHOICE is called from the main program and chooses components that may be formed in the system of given chemical composition as well as their stoichiometry. A data file for this routine is the DATABASE file.

Subroutine SOL is called from READWRITE.
and is the main calculating routine. It computes the equilibrium composition of the system at given $T$ and specified mass balance by searching for the global extremum of the Lagrangian function. It forms the Hessian matrix and calls various subroutines. Results of computations return to the READWRITE program to be written.

Subroutine SImpl is called from the SOL subroutine to enter new solid phases into the system and to invert the stoichiometric matrix. This calls the GG1 routine, which is the short version of the Gauss–Jordan matrix method.

Subroutine PITZER is called from the main program to choose data for Pitzer parameters and to calculate them at various temperatures if the freezing scenario has been chosen. It is also called from the SOL routine to calculate activity coefficients of species and water activity, using the Pitzer model at every iteration while minimizing the free energy function by Newton’s method. In FREZCHEM2, the PITZER subroutine, as well as the INTERACT subroutine published by Marion and Grant (1994), were used with only insignificant changes dealing mainly with the interface with data files.

Subroutine INTERACT calculates the higher-order electrostatic interactions for the Pitzer equations.

Subroutine GG is called from the SOL subroutine and solves the system of linear equations by the Gauss–Jordan method.

The principal flowchart of FREZCHEM2 is shown in Figure 1. The FREZCHEM2 model is a universal model that may be used to compute chemical equilibrium in any system consisting of one-component solids and/or aqueous solution. For this goal, only additions in the data files are needed.

Data files

Files that contain the information needed for calculations and some remarks are listed in Appendix B.

File DATABASE contains a list of independent components, which can be taken into account, and lists of aqueous solution species (cations, anions, neutral species including water) and solid phases, consisting of given independent components as well as their stoichiometry. For the convenience of users, the same species numbers (coding) were used as in the FREZCHEM model. If necessary, additional information may be added for independent components as well as for species and solids. Requested formats for entering new data could be taken from the listing of the READWRITE program (Appendix A).

File TABLE1 represents Table 1 of Spencer et al. (1990), which includes constants for the Debye–Hückel model parameter $A^0$ and for the binary interaction parameters as a function of temperature (K). File TABLE2 represents Table 2 of that paper for mixed-salt parameters. File TABLE3 contains coefficients for calculation of free energies of chemical reactions of formation for solids and ion pairs from aqueous solution species and liquid water as a function of temperature, using equations of the form published by Spencer et al. (1990):

$$
-\frac{\Delta G}{RT} = a_1 + a_2 T + a_6 T^2 + a_9 T^3
+ a_3 / T + a_4 \ln(T)
$$

and represents a copy of Table 3 from their paper. In this convention, free energies of cations, anions, and liquid water are taken to be equal to zero at any temperature.

Program input and output

Input to FREZCHEM2 is through the file INPUT, which contains the molal amounts of inde-
Table 1. FREZCHEM2 model input for freezing seawater from 0°C down to −40°C with a 2°C decrement.

<table>
<thead>
<tr>
<th>SMW seawater Title of the task</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.48695 Sodium (mol/kg)</td>
</tr>
<tr>
<td>0.01063 Potassium (mol/kg)</td>
</tr>
<tr>
<td>0.00953 Calcium (mol/kg)</td>
</tr>
<tr>
<td>0.05516 Magnesium (mol/kg)</td>
</tr>
<tr>
<td>0.56818 Chloride (mol/kg)</td>
</tr>
<tr>
<td>0.02939 Sulfate (mol/kg)</td>
</tr>
<tr>
<td>0.0 Carbonate (mol/kg)</td>
</tr>
<tr>
<td>0.0 Hydrogen (mol/kg)</td>
</tr>
<tr>
<td>273.15 initial temperature</td>
</tr>
<tr>
<td>1 freezing (2 for evaporation)</td>
</tr>
<tr>
<td>233.15 final temperature (final amount of water for evaporation)</td>
</tr>
<tr>
<td>2.0 temperature decrement (water decrement for evaporation)</td>
</tr>
</tbody>
</table>

Verification of the model

To verify the program, phase diagrams from Spencer et al. (1990) and point computations from Marion and Grant (1994) were recalculated. The model reproduces these computations with good accuracy. Table 4 shows the temperatures at the appearance of solids during seawater freezing, taken from Spencer et al. (1990) with an added column obtained by the FREZCHEM2 model using their thermodynamic data.

It is interesting to note that, according to the free energies of chemical reactions in the model, a solid reaction

\[ \text{NaCl} + 2\text{H}_2\text{O} \rightarrow \text{NaCl}_{(cr)} + 2\text{H}_2\text{O}_{(cr, l)} \]

takes place at temperatures lower than −57.15°C. To verify this independently, the heat capacity equations for these phases at low temperatures are needed.

LITERATURE CITED


Mironenko, M.V., and A.N. Salaskin (1991) PTX-
Table 2. FREZCHEM2 model output for freezing seawater at -45°C and at -55°C.

Seawater freezing
temperature -45.00°C (228.15 K)

### SOLID PHASES

<table>
<thead>
<tr>
<th>N</th>
<th>Phase</th>
<th>Moles</th>
<th>-G/RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H$_2$O(cr)</td>
<td>53.52785</td>
<td>-0.4278</td>
</tr>
<tr>
<td>2</td>
<td>NaCl*2H$_2$O(cr)</td>
<td>0.42624</td>
<td>1.0995</td>
</tr>
<tr>
<td>3</td>
<td>KCl(cr)</td>
<td>0.00948</td>
<td>-0.8002</td>
</tr>
<tr>
<td>4</td>
<td>MgCl$_2$·12H$_2$O(cr)</td>
<td>0.05052</td>
<td>1.2364</td>
</tr>
<tr>
<td>5</td>
<td>Na$_2$SO$_4$·10H$_2$O(cr)</td>
<td>0.02925</td>
<td>-12.2171</td>
</tr>
</tbody>
</table>

### AQUEOUS SOLUTION

<table>
<thead>
<tr>
<th>Ionic strength</th>
<th>Osmotic coefficient</th>
<th>Moles</th>
<th>Molality</th>
<th>Activity</th>
<th>Act. coef.</th>
<th>-G/RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.0759</td>
<td>2.0008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### BALANCE

<table>
<thead>
<tr>
<th>H$_2$O</th>
<th>Na$^+$</th>
<th>K$^+$</th>
<th>Ca$^{2+}$</th>
<th>Mg$^{2+}$</th>
<th>Cl$^-$</th>
<th>SO$_4^{2-}$</th>
<th>Total</th>
<th>Solids</th>
<th>Solution</th>
<th>Total computed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.555084E+02</td>
<td>0.486950E+00</td>
<td>0.106300E-01</td>
<td>0.953000E-02</td>
<td>0.551600E-01</td>
<td>0.568180E+00</td>
<td>0.293900E-01</td>
<td>0.65191D+00</td>
<td>0.0000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of iterations 93

Seawater freezing
temperature -55.00°C (218.15 K)

### SOLID PHASES

<table>
<thead>
<tr>
<th>N</th>
<th>Phase</th>
<th>Moles</th>
<th>-G/RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H$_2$O(cr,I)</td>
<td>53.63903</td>
<td>-0.5004</td>
</tr>
<tr>
<td>2</td>
<td>NaCl*2H$_2$O(cr)</td>
<td>0.42817</td>
<td>0.8123</td>
</tr>
<tr>
<td>3</td>
<td>KCl(cr)</td>
<td>0.00948</td>
<td>-0.8002</td>
</tr>
<tr>
<td>4</td>
<td>CaCl$_2$·6H$_2$O(cr)</td>
<td>0.00953</td>
<td>5.6614</td>
</tr>
<tr>
<td>5</td>
<td>MgCl$_2$·12H$_2$O(cr)</td>
<td>0.05052</td>
<td>1.2364</td>
</tr>
<tr>
<td>6</td>
<td>Na$_2$SO$_4$·10H$_2$O(cr)</td>
<td>0.02925</td>
<td>-12.2171</td>
</tr>
</tbody>
</table>

### BALANCE

<table>
<thead>
<tr>
<th>H$_2$O</th>
<th>Na$^+$</th>
<th>K$^+$</th>
<th>Ca$^{2+}$</th>
<th>Mg$^{2+}$</th>
<th>Cl$^-$</th>
<th>SO$_4^{2-}$</th>
<th>Total</th>
<th>Solids</th>
<th>Solution</th>
<th>Total computed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.555084E+02</td>
<td>0.486950E+00</td>
<td>0.106300E-01</td>
<td>0.953000E-02</td>
<td>0.551600E-01</td>
<td>0.568180E+00</td>
<td>0.293900E-01</td>
<td>0.65191D+00</td>
<td>0.0000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of iterations 93
Table 3. FREZCHEM2 model output for evaporation of seawater at 0°C.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>0.00°C (273.15 K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water amount</td>
<td>50.00 g</td>
</tr>
</tbody>
</table>

**SOLID PHASES**

<table>
<thead>
<tr>
<th>N</th>
<th>Phase</th>
<th>Moles -G/RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NaCl(cr)</td>
<td>0.28103 3.4448</td>
</tr>
<tr>
<td>2</td>
<td>Na₂SO₄·10H₂O(cr)</td>
<td>0.02021 -5.7260</td>
</tr>
</tbody>
</table>

**AQUEOUS SOLUTION**

| Ionic strength | 8.0709 |
| Osmotic coefficient | 1.5573 |

<table>
<thead>
<tr>
<th>N</th>
<th>Species</th>
<th>Moles</th>
<th>Molality</th>
<th>Activity</th>
<th>Act. coef. -G/RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Na⁺(aq)</td>
<td>0.16551D+00</td>
<td>0.35701D+01</td>
<td>0.28612D+01</td>
<td>0.8014 0.0000</td>
</tr>
<tr>
<td>2</td>
<td>K⁺(aq)</td>
<td>0.10630D-01</td>
<td>0.22929D+00</td>
<td>0.74428D-01</td>
<td>0.3264 0.0000</td>
</tr>
<tr>
<td>3</td>
<td>Ca²⁺</td>
<td>0.82305D-02</td>
<td>0.17754D+00</td>
<td>0.16740D+00</td>
<td>0.9429 0.0000</td>
</tr>
<tr>
<td>4</td>
<td>Mg²⁺</td>
<td>0.55155D-01</td>
<td>0.11897D+00</td>
<td>0.27250D+01</td>
<td>2.2905 0.0000</td>
</tr>
<tr>
<td>5</td>
<td>Cl⁻(aq)</td>
<td>0.28715D+00</td>
<td>0.61941D+01</td>
<td>0.10952D+01</td>
<td>1.7681 0.0000</td>
</tr>
<tr>
<td>6</td>
<td>SO₄²⁻(aq)</td>
<td>0.78786D-02</td>
<td>0.16995D+00</td>
<td>0.10190D-01</td>
<td>0.0600 0.0000</td>
</tr>
<tr>
<td>7</td>
<td>CaSO₄(aq)</td>
<td>0.12993D-02</td>
<td>0.28027D-01</td>
<td>0.28027D-01</td>
<td>1.0000 -2.7979</td>
</tr>
<tr>
<td>8</td>
<td>MgSO₄(aq)</td>
<td>0.53787D-05</td>
<td>0.11602D-03</td>
<td>0.11602D-03</td>
<td>1.0000 5.4788</td>
</tr>
<tr>
<td>9</td>
<td>H₂O(1)</td>
<td>0.25733D+01</td>
<td>0.72306D+00</td>
<td>0.0000</td>
<td></td>
</tr>
</tbody>
</table>

**BALANCE**

<table>
<thead>
<tr>
<th>Total</th>
<th>Solids</th>
<th>Solution</th>
<th>Total computed</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>0.277542E+01</td>
<td>0.202067E+00</td>
<td>0.257334E+01</td>
</tr>
<tr>
<td>Na⁺</td>
<td>0.486950E+00</td>
<td>0.321441E+00</td>
<td>0.165509E+00</td>
</tr>
<tr>
<td>K⁺</td>
<td>0.106300E-01</td>
<td>0.000000E+00</td>
<td>0.106300E-01</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>0.953000E-02</td>
<td>0.000000E+00</td>
<td>0.952987E-02</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>0.551600E-01</td>
<td>0.000000E+00</td>
<td>0.551600E-01</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>0.568180E+00</td>
<td>0.281028E+00</td>
<td>0.287154E+00</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>0.293900E-01</td>
<td>0.202067E-01</td>
<td>0.918331E-02</td>
</tr>
</tbody>
</table>

Number of iterations 45

Table 4. Temperatures (°C) of first appearance of solid phases on chilling of seawater.

<table>
<thead>
<tr>
<th>Solid</th>
<th>Experiment</th>
<th>Model⁸</th>
<th>FREZCHEM2 model⁸</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice</td>
<td>-1.921b</td>
<td>-1.924</td>
<td>-1.921</td>
</tr>
<tr>
<td>Mirabilite</td>
<td>-8.2c</td>
<td>-5.90</td>
<td>-5.87</td>
</tr>
<tr>
<td>Hydrohalite</td>
<td>-22.9c</td>
<td>-22.84</td>
<td>-22.87</td>
</tr>
<tr>
<td>Sylvite</td>
<td>-36c</td>
<td>-34.25</td>
<td>-34.30</td>
</tr>
<tr>
<td>MgCl₂·12H₂O</td>
<td>-36c</td>
<td>-36.82</td>
<td>-36.82</td>
</tr>
<tr>
<td>Antarticite</td>
<td>-54c</td>
<td>-53.64d</td>
<td>-53.73</td>
</tr>
</tbody>
</table>

b. Fujino et al. (1974).
d. Calculated in sulfate-free system.


APPENDIX A: FORTRAN LISTING OF THE FREZCHEM2 PROGRAM

PROGRAM READWRITE
IMPLICIT DOUBLE PRECISION (A-H,O-Z)

CHARACTER *40 NMC,NEL,NM,NMCOMP,TITLE

DIMENSION BAL(10),NEL(10),G0(40,6),G(40),GIN(40),BALS(10)
DIMENSION BALL(10),ACT(20)
DIMENSION BC(10,20),A(10,40),EX(40),NMC(20),NM(40),AIN(10,40)
DIMENSION IZC(20),IZ(20),NUM(40),NUMC(20),NUMIN(40),NMM(40)

COMMON /COMPNT/ NUR(I0),IP,NUL(10),IPNUL,KCOMP
COMMON /NUMBER/ NCAT,NANI,NNEI,NNM
COMMON /MASS1/ A,G,NUM,X(40)
COMMON /MASS2/ NM
COMMON /INTEGR/ NL,N,N1
COMMON /MATRIX/ ACT,UM,PHI,AH2O,IZ,IPP,NMV
COMMON /AIN/ AIN,GIN,T,NUMIN,IV
COMMON /OUTPUT/ JOPEN(10),IOPEN

10 FORMAT(A40)
11 FORMAT(A40/)
12 FORMAT(I3/)
13 FORMAT(A15,I3,1X,I2,A40,F12.6)
14 FORMAT(' THE CHARGE OF 1 KG OF THE SOLUTION IS EQUAL TO $,F8.5)
15 FORMAT(/13X,'Temperature ',F7.2,' C (' ,F7.2,') K')
16 FORMAT(' WATER AMOUNT ',F7.2,' GRAM')
17 FORMAT(25X,'SOLID PHASES'/1X,'N Phase ',
$ 16X,' Moles ',-G/RT')
18 FORMAT(I2,1X,A23,F9.5,2X,F12.4)
19 FORMAT(21X,'Ionic strength ',F8.4/
$ 21X,'Osmotic coefficient ',F7.4)
20 FORMAT(I1X,'N',2X,'Species ',4X,'Moles',7X,
$ ' Molality ',3X,'Activity ',Act.coef. -G/RT)
21 FORMAT(I2,1X,A16,3D12.5,2X,F8.4,F10.4)
22 FORMAT(I2,1X,A16,12X,5.12X,5.12X,8X,F10.4,)
23 FORMAT (26X,'BALANCE'/
$ 13X,'Total',9X,'Solids',8X,'Solution',5X,'Total computed')
24 FORMAT(1X,A8,4(2X,E12.6))
25 FORMAT(' Number of iterations ',I3)
26 FORMAT(' THE PROGRAM CANNOT CALCULATE THIS CHEMICAL $EQUILIBRIUM')

OPEN(1,FILE='DBASE')
OPEN(9,FILE='INPUT')
OPEN(10,FILE='RESULT')

XW=55.50837

READ(9,10) TITLE
WRITE(10,11) TITLE

11
C. READING INDEPENDENT COMPONENTS AND GIVING THE BALANCE

READ(1,12) KCOMP

C. THE WATER BALANCE (1 KG H2O = 55.50837 MOLES)

BAL(1)=XW
NEL(1)=‘H2O’
NUMIN(1)=1
NMM(1)=30
NM(1)=NEL(1)
NUR(1)=1
J=1
J1=0
CHARGE=0.

DO 2000 I=2,KCOMP
READ(1,13) NMCOMP,IIZ,NU
READ(9,*), AA
IF (AA.GT.1.D-20) THEN
   J=J+1
   BAL(J)=AA
   CHARGE=CHARGE+IIZ*AA
   NEL(J)=NMCOMP
   NM(J)=NEL(J)
   NMM(J)=NU
   NUMIN(J)=J
   NUR(J)=I
ELSE
   J1=J1+1
   NUL(J1)=I
END IF
2000 CONTINUE

IF (DABS(CHARGE) .GT. 0.0001) THEN
   WRITE(*,*) 'THE SALT BALANCE IS NOT CORRECT'
   WRITE(*,14) CHARGE
   IF (CHARGE.GT.0.)WRITE(*,*)'ADD ANIONS OR SUBT. CATIONS IN $INPUT'
   IF (CHARGE.LT.0.)WRITE(*,*)'ADD CATIONS OR SUBT. ANIONS IN $INPUT'
   PAUSE
   GO TO 815
END IF

IP=J
IPP=IP
IPNUL=J1

DO 2100 I=1,IP
   DO 2101 J=1,IP
      AIN(I,J)=0.
2101 CONTINUE

   AIN(I,I)=1.
   GIN(I)=0.
2100 CONTINUE
CALL CHOICE (NCAT, BC, NMC, NUMC, IZC)
NC=IP+NCAT

DO 2200 I=1, NCAT
   Il=I+IP
   DO 2201 J=1, IP
      AIN(J, Il)=BC(J, I)
   2201 CONTINUE
   NM(Il)=NMC(I)
   NMM(Il)=NUMC(I)
   NUMIN(Il)=Il
   IZ(Il)=IZC(I)
2200 CONTINUE

CALL CHOICE (NANI, BC, NMC, NUMC, IZC)
NA=NC+NANI

DO 2300 I=1, NANI
   Il=I+NC
   DO 2301 J=1, IP
      AIN(J, Il)=BC(J, I)
   2301 CONTINUE
   NM(Il)=NMC(I)
   NMM(Il)=NUMC(I)
   NUMIN(Il)=Il
   IZ(Il)=IZC(I)
2300 CONTINUE

CALL CHOICE (NNEI, BC, NMC, NUMC, IZC)
NL=NA+NNEI

DO 2400 I=1, NNEI
   Il=I+NA
   DO 2401 J=1, IP
      AIN(J, Il)=BC(J, I)
   2401 CONTINUE
   NM(Il)=NMC(I)
   NMM(Il)=NUMC(I)
   IF (NMM(Il) .EQ. 30) IV=Il
   NUMIN(Il)=Il
   IZ(Il)=IZC(I)
2400 CONTINUE

CALL CHOICE (NSOL, BC, NMC, NUMC, IZC)

DO 2500 I=1, NSOL
   Il=I+NL
   DO 2501 J=1, IP
      AIN(J, Il)=BC(J, I)
   2501 CONTINUE
NM(I1) = NMC(I)
NMM(I1) = NUMC(I)
NUMIN(I1) = I1

2500 CONTINUE

IP1 = IP + 1
L = NCAT + NANI + NNEI
N = NL + NSOL
N1 = N + 1

DO 2600 J = 1, IP
   AIN(J, N1) = BAL(J)
2600 CONTINUE

IJJ = 0

DO 2700 I = 1, N1
   NUM(I) = NUMIN(I)
2700 CONTINUE

C.................................................. READ TABLE 3 .................

OPEN(5, FILE='TABLE3')

DO 2800 I = IP + 1, N
   READ(5, *, END=2820) NT1

2810 IF (NMM(I) .EQ. NT1) THEN
   BACKSPACE(5)
   READ(5, *) NT1, (GO(I,K), K = 1, 6)
   REWIND(5)
ELSE
   GO TO 2810
END IF

2820 REWIND(5)
2800 CONTINUE

CLOSE (5)
CALL PITZER (T, 0, EX)
READ(9, *) TINIT
READ(9, *) IPATH

IF (IPATH .EQ. 1) THEN
   READ(9, *) TFIN
   READ(9, *) DT
ELSE
   READ(9, *) WFIN
   READ(9, *) DW
END IF

T = TINIT
BALWAT = 1000.

1 CONTINUE

DO 2900 I = IP + 1, N
   GIN(I) = PF(T, GO(I,1), GO(I,2), GO(I,3), GO(I,4), GO(I,5),
         GO(I,6))
2900 CONTINUE
IF(IPATH.EQ.1) WRITE(*,*) 'T=', T
PHI=1.
CALL PITZER (T,1,EX)

2 CONTINUE

IF(IPATH.EQ.2) WRITE (*,*) 'AMOUNT OF WATER=', BALWAT
CALL SOL (ICK,EX,ISOLU,IPATH)
TC=T-273.15
WRITE(10,15) TC,T
IF(IPATH.EQ.2) WRITE(10,16) BALWAT

IF(ICK.GT.400) GO TO 5
IF(IOPEN.GT.0) THEN
WRITE(10,17)

DO 3000 I=1,IOPEN
   J=JOPEN(I)
   WRITE(10,18) I,NM(NUM(J)),X(J),G(J)
3000 CONTINUE

END IF
IF(ISOLU.EQ.0) GO TO 4

C.............................. START OF OUTPUT ......................
WRITE(10,*), 'AQUEOUS SOLUTION'
WRITE(10,19) UM, PHI
WRITE(10,20)
DO 3100 K=IP1,NL-1
   EX(K)=EX(K)*XW
   G(K)=G(K)-DLOG(XW)
   AC=EXP(ACT(K))
   WRITE (10,21) K-IP,NM(K),X(K),EX(K),EX(K)*AC,AC,G(K)
3100 CONTINUE

WRITE(10,22) NL-IP,NM(NL),X(NL),DEXP(AH2O),G(NL)

4 WRITE(10,23)
DO 3200 K=1,IP
   BALL(K)=0.
   BALS(K)=0.
3200 CONTINUE

DO 3300 I=1,IOPEN
   J=JOPEN(I)
   DO 3301 K=1,IP
      BALS(K)=BALS(K)+X(J)*AIN(K,NUM(J))
3301 CONTINUE
3300 CONTINUE

15
DO 3400 I=1,IP
    DO 3401 J=IP1,NL
        BALL(I)=BALL(I)+X(J)*AIN(I,J)

3401 CONTINUE

WRITE(10,24)NEL(I),AIN(I,NL),BALS(I),BALL(I),BALS(I)+BALL(I)

3400 CONTINUE

5 WRITE(10,25) ICK

C................................. FINISH ............................

IF(ICK.GT.400) WRITE (10,26)

IF (IPATH.EQ.1) THEN
    T=T-DT
    IF(T.GE.TFIN-.001) GO TO 1
ELSE
    BALWAT=BALWAT-DW
    IF(BALWAT.GE.WFIN) THEN
        AIN(1,NL)=BALWAT/18.0153
        GO TO 2
    END IF
END IF

CLOSE(3)

815 STOP
END

C.................................C

C.................................C

SUBROUTINE CHOICE (NCAT,BK,NMCUR,NUMCUR,IZC)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C.. SUBROUTINE FOR CHOOSING COMPONENTS FROM DATABASE ACCORDING TO
C.. THE GIVEN INDEPENDENT COMPONENTS

CHARACTER *40 NM,NMCUR
DIMENSION BK(10,20),NMCUR(20),NUMCUR(20),IZC(20),B(10)
COMMON /COMPNT/ NUR(10),IP,NUL(10),IPNUL,KCOMP

3 FORMAT(A23,I2,I2,I2,1X,10F6.2)

READ(1,*)NCAT
J=0

DO 2 I=1,NCAT
     READ(1,3) NM,NUM,IZ, (B(I1),I1=1, KCOMP)
     READ(1,*) NM,NUM,IZ, (B(I1),I1=1, KCOMP)

2    DO 2000 J1=1,IPNUL
      IF (B(NUL(J1)).NE.0.) GO TO 2

2000 CONTINUE
IS=0
DO 3000 J1=1,IP
   IF (DABS(B(NUR(J1))).GT.1D-20) IS=IS+1
3000 CONTINUE

IF (IS.EQ.0) GO TO 2
J=J+1
DO 4 J1=I,IP
   BK(J1,J)=B(NUR(J1))
4 CONTINUE
NMCUR(J)=NM
NUMCUR(J)=NUM
IZC(J)=IZ
2 CONTINUE
NCAT=J
RETURN
END

SUBROUTINE INTACT(ZI,Z2,UM,A,PHIPHI,PHIPRI,PHIIJ,THETA)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION B(0:22), D(0:22), ZA(2), XA(2,2),XJ(2,2),XJPRIM(2,2)
DIMENSION AKI(0:20), AKII(0:20)
DATA AKI/1.925154014814667, -0.060076477753119,
$ -0.00636874599598, 0.000036583601823, -0.000045036975204,
$ -0.000004537895710, 0.000000396566462, 0.00000013522610,
$ 0.00000001229405, -0.00000000821969, -0.0000000050847,
$ 0.00000000463133, 0.0000000001943, -0.000000002563,
$ -0.0000000010991/
DATA AKII/0.628023320520852, 0.462762985338493,
$ 0.150044637187895, -0.028796057604906, -0.036552745910311,
$ -0.001668087945272, 0.006519840398744, 0.001130378079086,
$ -0.000887171310131, -0.000242107641309, 0.000087294451594,
$ 0.000036862122751, -0.000004583768938, -0.00003548684306,
$ -0.0000000250453880, 0.0000000216991779, -0.000000080779570,
$ 0.000000004558555, -0.00000006944757, -0.00000002849257,
$ 0.00000000237816/
B(21)=0.
B(22)=0.
D(21)=0.
D(22)=0.
ZA(1)=Z1
ZA(2)=Z2
SQ=SQRT(UM)
DO 2000 J=1,2

DO 2001 I =1,2
    XA(J,I)=6.*ZA(I)*ZA(J)*A*SQ
    X=XA(J,I)
    IF (X.LT.1.) THEN
        ZZ=4.*X**0.2-2.0
        DZ=.8*X**(-.8)
    ELSE
        ZZ=40./9.*X**(-.1)-22./9.
        DZ=-40./90.*X**(-1.1)
    END IF

DO 2002 K=20,0,-1
    B(K)=ZZ*B(K+1)-B(K+2)+AKI(K)
    D(K)=B(K+1)+ZZ*D(K+1)-D(K+2)
2002 CONTINUE

IF (XJPRIM(J,I)=.25+.5*DZ*(D(0)-D(2))
2001 CONTINUE

ETHETA=(Z1*Z2/4./UM)*(XJ(1,2)-.5*XJ(1,1)-.5*XJ(2,2))
ETHPRI=-ETHETA/UM+(Z1*Z2/8./UM**2)*(XA(1,2)*XJPRIM(1,2)-
$ .5*XA(1,1)*XJPRIM(1,1)-.5*XA(2,2)*XJPRIM(2,2))
PHIIJ=THETA+ETHETA
PHIPHI=ETHPRI
PHIPRI=ETHPRI
RETURN
END

C-----------------------------------------
C
SUBROUTINE PITZER (T,IFLAG,EX)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION AOM(6),NMM(40),NAQ(20),Z(20),EX(20)
DIMENSION BPRIM(10,10),BPHI(10,10),C(10,10),PHIJI(10,10),
$ SUMCA(10),SUMCAT(10),SUMAN(10),SUMZ(10),SUMAC(10),ACT(20),
$ PHIIJ(10,10),PHIPHI(10,10),XM(40),IZ(20)
DIMENSION SUMAA(10),SUMCC(10),SUMK(10)
DIMENSION BETO(10,10),BET1(10,10),C0(10,10),BET2(10,10),
$ TET(10,10),PSI(10,10,10),B(10,10)
DIMENSION BETOM(10,10,6),BET1M(10,10,6),COM(10,10,6),
$ BET2M(10,10,6),TETM(10,10,6),PSIM(10,10,10,6)
COMMON /NUMBER/NCAT,NANI,NNBI,NMM
COMMON /MATRIX/ ACT, UM, PHI, AH2O, IZ, IP, NM

IF (IFLAG.EQ.1) GO TO 1
IF (IFLAG.EQ.2) GO TO 2

ICOL=6
NN=NCAT+NANI
NC1=NCAT+1

DO 2000 I=1,NN
   Z(I)=IZ(I+IP)
   NAQ(I)=NMM(I+IP)
2000 CONTINUE

C.............................. READ TABLES 1 AND 2 ..............................

OPEN(3, FILE='TABLE1')

C.............................. READ TABLE 1 ......................................

DO 3000 I=1,NN
   DO 3001 J=1,NN
      DO 3002 K=1,6
         COM(I,J,K)=0.
         BET2M(I,J,K)=0.
      3002 CONTINUE
   3001 CONTINUE
3000 CONTINUE

READ(3,*) (AOM(I), I=1,6)

DO 4000 I=1,NCAT
   DO 4001 J=NC1,NN
      101 READ(3,FMT='(213)') NT1, NT2

   IF (NAQ(I).EQ.NT1.AND.NAQ(J).EQ.NT2) THEN
      READ(3,*) (BETOM(I,J,K), K=1,6)
      READ(3,*) (BET1M(I,J,K), K=1,6)
   END IF

   ELSE
      READ(3,*) (COM(I,J,K), K=1,6)
   END IF

   ELSE
      IF ((NT1.EQ.3 .OR. NT1.EQ.4) .AND. NT2.EQ.12) THEN
         READ(3, FMT='(///)', END=910)
      ELSE
         READ(3, FMT='(///)', END=910)
      END IF

   END IF
910 CONTINUE
GO TO 101

END IF

4001  CONTINUE

4000  CONTINUE

CLOSE(3)

C......................... READ TABLE 2 .........................

OPEN(4, FILE='TABLE2')

DO 5000 I=1,NCAT-1

   DO 5001 J=I+1,NCAT
   102 READ(4,* ) NT1,NT2,NT3

      IF(NAQ(I) .EQ. NT1 .AND. NAQ(J) .EQ. NT2 .AND. NT3 .EQ. 0) THEN
         BACKSPACE(4)
         READ(4,* ) NT1,NT2,NT3,(TETM(I,J,K),K=1,6)
         REWIND(4)
      ELSE
         GO TO 102
      END IF

   5001 CONTINUE

5000 CONTINUE

DO 6000 I=1,NCAT-1

   DO 6001 J=I+1,NCAT

      DO 6002 IJ = NC1,NN
      105 READ(4,* ) NT1,NT2,NT3

      IF (NAQ(I) .EQ. NT1 .AND. NAQ(J) .EQ. NT2 .AND. NAQ(IJ) .EQ. NT3) THEN
         BACKSPACE(4)
         READ(4,* ) NT1,NT2,NT3,(PSIM(I,J,IJ,K),K=1,6)
         REWIND(4)
      ELSE
         GO TO 105
      END IF

6002 CONTINUE

6001 CONTINUE

6000 CONTINUE

DO 7000 I=NC1,NN-1

   DO 7001 J=I+1,NN
   103 READ(4,* ) NT1,NT2,NT3
IF(NAQ(I) .EQ. NT1 .AND. NAQ(J) .EQ. NT2 .AND. NT3.EQ.0) THEN
BACKSPACE(4)
READ(4,*) NT1,NT2,NT3,(TETM(I,J,K),K=1,6)
REWIND(4)
ELSE
GO TO 103
END IF
7001 CONTINUE
7000 CONTINUE
DO 8000 I=NC1,NN-1
DO 8001 J=I+1,NN
DO 8002 IA=1,NCAT
106 READ(4,*) NT1,NT2,NT3
IF(NAQ(I) .EQ. NT1 .AND. NAQ(J) .EQ. NT2 .AND. NAQ(IA) .EQ. NT3) THEN
BACKSPACE(4)
READ(4,*) NT1,NT2,NT3,(PSIM(I,J,IA,K),K=1,6)
REWIND(4)
ELSE
GO TO 106
END IF
8002 CONTINUE
8001 CONTINUE
8000 CONTINUE
104 CLOSE(4)
C.............................. END OF READING ..............................
RETURN
1 CONTINUE
C.. CALCULATION OF VALUES OF THE PARAMETERS FOR CURRENT TEMPERATURE

A0= PF(T,A0M(1),A0M(2),A0M(3),A0M(4),A0M(5),A0M(6))
DO 9000 I=1,NCAT
DO 9001 J=1,NN
BETO(I,J)= PF(T,BETOM(I,J,1),BETOM(I,J,2),BETOM(I,J,3),BETOM(I,J,4),BETOM(I,J,5),BETOM(I,J,6))
BET1(I,J)= PF(T,BET1M(I,J,1),BET1M(I,J,2),BET1M(I,J,3),BET1M(I,J,4),BET1M(I,J,5),BET1M(I,J,6))
BET2(I,J)= PF(T,BET2M(I,J,1),BET2M(I,J,2),BET2M(I,J,3),BET2M(I,J,4),BET2M(I,J,5),BET2M(I,J,6))
CO(I,J)= PF(T,COM(I,J,1),COM(I,J,2),COM(I,J,3),COM(I,J,4),COM(I,J,5),COM(I,J,6),
$\text{COM}(I,J,4),\text{COM}(I,J,5),\text{COM}(I,J,6)\) }

\begin{verbatim}
9001 CONTINUE
9000 CONTINUE

DO 10000 I=1,NN-1
    DO 10001 J=I+1,NN
        TET(I,J)= PF(T,TETM(I,J,1),TETM(I,J,2),TETM(I,J,3),
                   TETM(I,J,4),TETM(I,J,5),TETM(I,J,6))
    \end{verbatim}

\begin{verbatim}
DO 10002 IA=1,NN
    PSI(I,J,IA)=PF(T,PSIM(I,J,IA,1),PSIN(I,J,IA,2),
                   PSIN(I,J,IA,3),PSIM(I,J,IA,4),
                   PSIM(I,J,IA,5),PSIM(I,J,IA,6))
\end{verbatim}

\begin{verbatim}
10002 CONTINUE
10001 CONTINUE
10000 CONTINUE
RETURN
\end{verbatim}

\begin{verbatim}
2 CONTINUE

DO 11000 I = 1, 10
    SUMCA(I) = 0.
    SUMCAT(I) = 0.
    SUMAN(I) = 0.
    SUMZ(I) = 0.
    SUMAC(I) = 0.
    SUMAA(I) = 0.
    SUMCC(I) = 0.
    SUMK(I) = 0.

11000 CONTINUE

SMX=0.
ZZ=0.
UM=0.

DO 12000 I=IP+1,NMV
    J=I-IP
    XM(J)=EX(I)*55.50837
    ZZ=ZZ+XM(J)*DABS(Z(J))
    UM=UM+XM(J)*Z(J)**2
SMX=SMX+XM(J)

12000 CONTINUE

UM=UM/2.
SQ=SQRT(UM)
ALPHA=2.*SQ
ALPHA1=1.4*SQ
ALPHA2=12.*SQ
G1=2.*(1.-(1.+ALPHA1)*EXP(-ALPHA1))/ALPHA1**2
G2=2.*(1.-(1.+ALPHA2)*EXP(-ALPHA2))/ALPHA2**2
GPR11=-2.*(1.-(1.+ALPHA1+ALPHA1**2/2.)*EXP(-ALPHA1))/ALPHA1**2
GPR12=-2.*(1.-(1.+ALPHA2+ALPHA2**2/2.)*EXP(-ALPHA2))/ALPHA2**2
G=2.*(1.-(1.+ALPHA)*EXP(-ALPHA))/ALPHA**2
GPRIME=-2.*(1.-(1.+ALPHA+ALPHA**2/2.)*EXP(-ALPHA))/ALPHA**2
\end{verbatim}

22
DO 13000 J=1,NCAT
  DO 13001 I=NC1,NN
    IF (Z(J)*ABS(Z(I)).EQ.4) THEN
      BPHI(J,I)=BETO(J,I)+BET1(J,I)*EXP(-ALPHA1)+
                  BET2(J,I)*EXP(-ALPHA2)
      B(J,I)=BETO(J,I)+BET1(J,I)*G1+BET2(J,I)*G2
      BPRIME(J,I)=BET1(J,I)*GPRI1/UM+BET2(J,I)*GPRI2/UM
    ELSE
      BPHI(J,I)=BETO(J,I)+BET1(J,I)*EXP(-LPHA)
      B(J,I)=BETO(J,I)+BET1(J,I)*G
      BPRIME(J,I)=BET1(J,I)*GPRIME/UM
    END IF
  C(J,I)=C0(J,I)/2./SQRT(Z(J)*DABS(Z(I))
13001 CONTINUE
13000 CONTINUE
  DO 14000 J=1,NCAT-1
    DO 14001 I=J+1,NCAT
      CALL INTACT(Z(J),Z(I),UM,A0,PHIPHI(J,I),
                  PHIPRI(J,I),PHIIJ(J,I),TET(J,I))
14001 CONTINUE
14000 CONTINUE
  DO 15000 J=NC1,NN-1
    DO 15001 I=J+1,NN
      CALL INTACT(Z(J),Z(I),UM,A0,PHIPHI(J,I),
                  PHIPRI(J,I),PHIIJ(J,I),TET(J,I))
15001 CONTINUE
15000 CONTINUE
C.. CALCULATION OF SUMMATION TERMS FOR F AND PHI.
  SCATON=0.
  SUBSUM=0.
  SANON=0.
  SUMCAF=0.
  SUMANF=0.
  DO 16000 J=1,NCAT-1
    DO 16001 J1=J+1,NCAT
      DO 16002 I=NC1,NN
        SUBSUM=SUBSUM+PSI(J,J1,I)*XM(I)
16002 CONTINUE
      SCATON=SCATON+(SUBSUM+PHIPHI(J,J1))*XM(J)*XM(J1)
      SUMCAF=SUMCAF+PHIPRI(J,J1)*XM(J)*XM(J1)
      SUBSUM=0.
16001 CONTINUE
16000 CONTINUE
SUBSUM=0.
DO 17000 J=NC1,NN-1
   DO 17001 J1=J+1,NN
      DO 17002 I=1,NCAT
         SUBSUM=SUBSUM+PSI(J,J1,I)*XM(I)
      17002 CONTINUE
SANON=SANON+(SUBSUM+PHIPHI(J,J1))*XM(J)*XM(J1)
SUMANF=SUMANF+PHIPRI(J,J1)*XM(J)*XM(J1)
SUBSUM=0.
17001 CONTINUE
17000 CONTINUE

18000 CONTINUE
SUMB=0.
SUMPHI=0.
DO 18000 J=1,NCAT
   DO 18001 I=NC1,NN
      SUMB=SUMB+XM(J)*XM(I)*BPRIME(J,I)
      SUMPHI=SUMPHI+XM(J)*XM(I)*(BPHI(J,I)+ZZ*C(J,I))
   18001 CONTINUE
18000 CONTINUE
FIN=-A0*(SQ/(1.+1.2*SQ)+2.*DLOG(1.+1.2*SQ)/1.2)+
     SUMB+SUMCAF+SUMANF
PHI=1.+2./SMX*(-A0*UM**1.5/(1.+1.2*SQ)+SUMPHI+SCATON+SANON)
AH20=-PHI*SMX/55.50837

C...... CALCULATION OF TERMS FOR ACTIVITY COEFFICIENTS(GAMMA)....... 
SUM=0.
DO 19000 J=1, NCAT-1
   DO 19001 J1=J+1, NCAT
      DO 19002 I=NC1,NN
         PSI(J1,J,I)=PSI(J,J1,I)
      19002 CONTINUE
      PHIJJ(J1,J)=PHIJJ(J,J1)
   19001 CONTINUE
19000 CONTINUE

20000 CONTINUE
DO 20000 I=NC1, NN-1
   DO 20001 I1=I+1, NN
      DO 20002 J=1, NCAT
         PSI(I1,I,J)=PSI(I,I1,J)
   20002 CONTINUE 
20001 CONTINUE
20000 CONTINUE

DO 21000 J=1, NCAT
    DO 21001 I=NC1, NN
      SUMCA(J)=SUMCA(J)+XM(I)*(2.*(B(J,I))+ZZ*C(J,I))
    CONTINUE
  END DO 21000

DO 22000 J=1, NCAT
    DO 22001 J1=NC1, NN-1
      DO 22002 I=J1-4, NN
        SUMAN(J)=SUMAN(J)+XM(I)*X4(I)*PSI(J, I, J)
      CONTINUE
    CONTINUE
  CONTINUE

DO 23000 J=1, NCAT
    DO 23001 J1=NC1, NN-1
      DO 23002 I=J1+1, NN
        SUMAN(J)=SUMAN(J)+XM(I)*X4(I)*PSI(J, I, J)
      CONTINUE
    CONTINUE
  CONTINUE

SUM=0.
DO 24000 J=1, NCAT
    SUM=SUM+XM(J)*YM(I)*C(J, I)
  CONTINUE

DO 25000 J=1, NCAT
  SUMZ(J)=SUM*DABS(Z(J))
  ACT(J+1P)=Z(J)**2*F+SUMCA(J)+SUMCAT(J)+SUMAN(J)+SUMZ(J)
26000 CONTINUE

SUM=0.

DO 27000 I=NC1, NN

   DO 27001 J=1, NCAT
      SUMAC(I)=SUMAC(I)+XM(J)*(2.*(B(J,I))+ZZ*C(J,I))
   27001 CONTINUE

27000 CONTINUE

DO 28000 I=NC1, NN

   DO 28001 J=1, NCAT
      SUM=SUM+XM(J)*PSI(I,I1,J)
   28001 CONTINUE

   SUMAA(I)=SUMAA(I)+XM(I1)*(SUM+2.*PHIIJ(I,I1))

28000 CONTINUE

DO 29000 I=NC1, NN

   DO 29001 J=1, NCAT-1
      DO 29002 J1=J+1, NCAT
         SUMCC(I)=SUMCC(I)+XM(J)*XM(J1)*PSI(J,J1,I)
      29002 CONTINUE
   29001 CONTINUE

29000 CONTINUE

SUM=0.

DO 30000 J=1, NCAT

   DO 30001 I=NC1, NN
      SUM=SUM+XM(J)*XM(I)*C(J,I)
   30001 CONTINUE

30000 CONTINUE

SUMK(I)=SUM*ABS(Z(I))

31000 CONTINUE

DO 32000 J=NC1, NN

   ACT(J+IP)=Z(J)**2+F+SUMAC(J)+SUMAA(J)+SUMCC(J)+SUMK(J)

32000 CONTINUE

DO 33000 I=1, NMV-IP

   IF(ACT(I+IP).GT.ALOG(10000.)) ACT(I+IP)=AALLOC(10000.)

33000 CONTINUE

26
SUBROUTINE SIMPL (IP1,M,IOPI,IP,N1,K,IR)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
COMMON /MASS1/ A,G,NUM,X(40)
COMMON /ENTER/ ISIM,ISIMIN
DIMENSION A(10,40),G(40),NUM(40)
C
C     IP1 - BEGINING J, M - FINISH J, IOPI- BEGINING I, IP -FINISH I
C
C    LOOKING FOR A NEW PHASE FOR INCLUDING INTO BASIS.........

ISIM=0
1111  DEL=0.DO
       IH=0
       K=0
       DO 1001 J=IP1,M
            P=0.
                DO 1002 I=IH,IP
                    P=P+G(I)*A(I,J)
1002   CONTINUE
            DELTA=G(J)-P
            IF(DELTA.GE.DEL) GO TO 1001
            DEL=DELTA
            K=J
            ISIM=1
1001   CONTINUE
       IF(K.EQ.0) GO TO 1000
C
C    LOOKING FOR PLACE IN THE BASIS TO BE SUBSTITUTED............

BMIN=1D+20
       DO 1005 I=IOPI,IP
            IF(A(I,K).LE.0.) GO TO 1005
            BTEK=A(I,N1)/A(I,K)
            IF(BTEK.GE.BMIN) GO TO 1005
            BMIN=BTEK
            IR=I
1005  CONTINUE
       DO 1007 I=IH,IP
            A(I,IR)=A(I,K)
1007  CONTINUE
NUM(IR) = NUM(K)
G(IR) = G(K)
CALL GGI(IR, IP+1, IP, N1)

C.. IF(ISIMTN.EQ.0) GO TO 1111

1000 CONTINUE
RETURN
END

C------------------------------------------

C------------------------------------------

SUBROUTINE GGI(ICOL, IP1, IPS, N1)
DOUBLE PRECISION A, G, X
DIMENSION A(10, 40), G(40), NUM(40)
COMMON /MASS1/ A, G, NUM, X(40)

DO 1 I = IP1, N1
   A(ICOL, I) = A(ICOL, I) / A(ICOL, ICOL)
1 CONTINUE
A(ICOL, ICOL) = 1.

DO 2 J = 1, IPS
   IF(J.EQ.ICOL) GO TO 2
   DO 3 I = IP1, N1
      A(J, I) = A(J, I) - A(ICOL, I) * A(J, ICOL)
3 CONTINUE
   A(J, ICOL) = 0.
2 CONTINUE
RETURN
END

C------------------------------------------

C------------------------------------------

SUBROUTINE GG(INI, NP, NP1)
DOUBLE PRECISION P1, AM, AT
COMMON/COMGG/ P1(20, 21)

DO 201 I = INI, NP
   AM = P1(I, I)
   II = I
   IJ = I + 1
   DO 202 K = IJ, NP
      IF(ABS(AM) .GE. DABS(P1(K, I))) GO TO 202
      AM = P1(K, I)
      II = K
202 CONTINUE
DO 203 I = 1, NP1
    AT = P1(I1, K)
    P1(I1, K) = AT / AM
    P1(I, K) = P1(I, K)
    P1(I, K) = P1(I, K) - P1(I, K) * AM
203 CONTINUE

DO 241 J = INIT, NP
    AM = P1(J, I)
    IF(J.EQ.I) GO TO 241
    DO 204 K = I, NP1
        P1(J, K) = P1(J, K) - P1(I, K) * AM
204 CONTINUE
241 CONTINUE
201 CONTINUE

RETURN
END

C C
C C
C.. THE ROUTINE FOR CALCULATION OF CHEMICAL EQUILIBRIA
C.. IN WATER-SALT SYSTEMS AT THE TEMPERATURE RANGE 25-60 C.
DOUBLE PRECISION FUNCTION PF(T, A1, A2, A6, A9, A3, A4)
IMPLICIT DOUBLE PRECISION (A-H, O-Z)
PF = A1 + A2 * T + A6 * T**2 + A9 * T**3 + A3 / T + A4 * LOG(T)
RETURN
END

C C
C C
SUBROUTINE SOL (ICK, EX, ISOLU, IPATH)
IMPLICIT DOUBLE PRECISION (A-H, O-Z)
CHARACTER * 40 NM
DIMENSION G(40), X(40), EX(20), EXTMP(20), A(10, 40), ACT(20), NM(40)
DIMENSION JOPEN(10), JCLOSE(10), SU(20), P1(20, 21), AIN(10, 40)
DIMENSION NUMIN(40), NUM(40), GIN(40), ACTT(20), IZ(20)
COMMON /NUMBER/ NCA, NANI, NNEI, NUM(40)
COMMON /MASS1/ A, G, NUM, X
COMMON /MASS2/ NM
COMMON /INTGER/ NL, N, N1
COMMON /MATRIX/ ACT, UM, PHI, AH20, IZ, IP, NMV
COMMON /AIN/ AIN, GIN, T, NUMIN, IV
COMMON /COMGG/ P1
COMMON /ENTER/ ISIM, ISIMIN
COMMON /OUTPUT/ JOPEN, IOPEN

DO 1000 I = 1, 20
    ACT(I) = 0. DO
1000 CONTINUE

29
ISIMIN=1
ISOLU=1
ICK=0
ICE=0
XW=55.50837

DO 2000 I = 1, 10
   DO 2001 J = 1, 40
      A(I,J)=AIN(I,J)
   2001 CONTINUE
2000 CONTINUE

DO 2100 I = 1, 40
   NUM(I)=NUMIN(I)
   G(I)=GIN(I)
2100 CONTINUE

EPS=.001
IP1=IP+1
NUM(N1)=N1
NM(N1)='DEL'
PHI=1.
IP1=IP+1
NL1=NL+1
L=NL-IP
NMV=NL-1
N1=N+1

DO 2200 I=IP1,NMV
   G(I)=G(I)+DLOG(XW)
2200 CONTINUE

DO 2300 I=1,IP
   DO 2301 J=IP1,NL
      IF(NM(N1).EQ.NM(J)) THEN
         NUM(I)=J
         NUMIN(I)=J
         G(I)=G(J)
      END IF
2301 CONTINUE

IF(NM(N1).EQ.30) THEN
   IVV=I
   X(IV)=A(I,N1)
END IF
2300 CONTINUE

SUM=0.DO

DO 2400 I=1,IP
   NI=NUM(I)
   IF (I.NE.IVV) THEN
      X(NI)=A(I,N1)
      EX(NI)=A(I,N1)/X(IV)
      G(I)=G(NUM(I))+DLOG(EX(NUM(I)))
   END IF
2400 CONTINUE
END IF
2400 CONTINUE

CALL PITZER (T,2,EX)
G(IVV)=AH2O

DO 2500 I=1,IP
   NI=NUM(I)
   IF (I.NE.IVV) THEN
      G(I)=G(NI)+DLOG(EX(NI))+ACT(NI)
   END IF
2500 CONTINUE

DO 2600 J=IP1,NMV
   SU(J)=-G(J)
      DO 2601 K=1,IP
         SU(J)=SU(J)+A(K,J)*G(K)
      2601 CONTINUE
   EX(J)=DEXP(SU(J)-ACT(J))
   X(J)=X(IV)*EX(J)
2600 CONTINUE

CALL SIMPL (NL1,NL,1,IP,N1,IK,IR)
DELL1:1.
75 CONTINUE
76 ICLOS=0
IOPEN=0

DO 2700 I=1,IP
      IF (NUM(I).GE.NL1.AND.NUM(I).LE.N) THEN
         IOPEN=IOPEN+1
         JOPEN(IOPEN)=I
      ELSE
         ICLOS=ICLOS+1
         JCLOS(ICLOS)=I
      END IF
2700 CONTINUE

IF (IOPEN.GT.0) THEN
      IF (IOPEN.EQ.1.AND.NMM(NUM(JOPEN(1))).EQ.31) THEN
         ICE=1
         SU(IV)=-G(IV)
      DO 2800 K=1,IP
         SU(IV)=SU(IV)+A(K,IV)*G(K)
      2800 CONTINUE
         XMN=1.
      DO 2900 K=1,10
         XMN=XMN*1.5
         DO 2901 J=IP1,NMV
            EXTMP(J)=EX(J)*XMN
            SUMS=SUMS*XMN
      2901 CONTINUE
31
CALL PITZER (T,2,EXTMP)
IF (AH2O.LE.SU(IV)) GO TO 10

2900 CONTINUE

10 X(IV)=X(IV)/XMNY*1.2

DO 3000 I=1,ICLOS
  J=JCLOS(I)
  NJ=NUM(J)
  EX(NJ)=EXTMP(NJ)/1.2
  G(J)=G(NJ)+DLOG(EX(NJ))+ACT(NJ)
3000 CONTINUE

ELSE
  DO 3200 I=1,IP
    DO 3201 J=IP1,NL
      IF(NUMIN(I).EQ.J) THEN
        X(J)=X(J)-.95*A(IR,N1)*AIN(I,IK)
        IF(X(J).LE.0.)X(J)=1.E-5
      END IF
    3201 CONTINUE
3200 CONTINUE

IF(ICE.EQ.1) THEN
  SU(IV)=-G(IV)
  DO 3300 K=1,IP
    SU(IV)=SU(IV)+A(K,IV)*G(K)
  3300 CONTINUE
  III=0
END IF

11 DO 3400 J=IP1,NMV
  EX(J)=X(J)/X(IV)
3400 CONTINUE

III=III+1

CALL PITZER (T,2,EX)

IF(ICE.EQ.1.AND.IPATH.EQ.1) THEN
  IF(AH2O.GT.SU(IV)) THEN
    X(IV)=X(IV)/1.2
    GO TO 11
  ELSE
    IF(III.GT.1)X(IV)=X(IV)*1.1
  END IF
END IF

DO 3500 I=1,ICLOS
  J=JCLOS(I)
  NJ=NUM(J)
  IF(NJ.LT.NL) G(J)=G(NJ)+DLOG(EX(NJ))+ACT(NJ)
3500 CONTINUE
DO 3600 J=IP1,NMV
   SU(J)=-G(J)
   DO 3601 K=1,IP
      SU(J)=SU(J)+A(K,J)*G(K)
   3601 CONTINUE
   IF(J.NE.IV) EX(J)=DEXP(SU(J)-ACT(J))
   X(J)=EX(J)*X(IV)
3600 CONTINUE
END IF
END IF

IN=ICLOS+L
IN1=IN+1
5 IF(ICK.GT.400) RETURN
ICK=ICK+1
C. EXAMINE FOR AQUEOUS SOLUTION PRESENCE............
IF(ICLOS.LE.1) THEN
   ISOLU=0
   DO 3700 I=IP1,NL
      X(I)=0.
   3700 CONTINUE
   GO TO 400
END IF
ISL=0
DO 3800 J=IP1,NL
   SU(J)=G(J)
   DO 3801 K=1,IP
      SU(J)=SU(J)-A(K,J)*G(K)
   3801 CONTINUE
   EX(J)=X(J)/X(IV)
   ACTT(J)=ACT(J)
   IF(IS.EQ.1)ACTT(J)=0.
3800 CONTINUE
   IS=IS+1
   PHITT=PHI
   CALL Pitzer(T,2,EX)
   PHI=(PHITT+PHI)/2
   SUM=0.
   DO 3900 J=IP1,NMV
      ACT(J)=(ACT(J)+ACTT(J))/2.
      JI=J-IP
      P1(JI,JI)=1./X(J)
3900 CONTINUE
\[ P_{1}(J, N)=D \log (X(J))+\text{ACT}(J)-D \log (X(I))+S_{u}(J) \]
\[ P_{1}(J, L)=-1./X(I) \]
\[ P_{1}(L, J)=-1./X(I) \times \Phi \]
\[ \text{SUM}=\text{SUM}+E X(J) \]

\[ P_{1}(L, L)=\text{SUM} \times \Phi /X(I) \]
\[ P_{1}(L, N)=S_{u}(N)-\text{SUM} \times \Phi \]

\[ \text{DO } 4000 \text{ I}=1,\text{ICLOS} \]
\[ X=L+I \]
\[ II=J \text{CLOS}(I) \]
\[ P_{1}(K, K)=0. \]
\[ P_{1}(K, N)=A(II, N) \]

\[ \text{DO } 4001 \text{ J}=I+1,\text{NL} \]
\[ P_{1}(K, N)=P_{1}(K, N)+A(II, J) \times X(J) \]
\[ IJ=J-I \]
\[ P_{1}(K, I)=A(II, J) \]
\[ P_{1}(I, K)=-A(II, J) \]

\[ 4001 \text{ CONTINUE} \]

\[ 4000 \text{ CONTINUE} \]

\[ \text{CALL GG}(1, IN, IN) \]

\[ \text{DO } 4100 \text{ I}=1,\text{ICLOS} \]
\[ K=L+I \]
\[ II=J \text{CLOS}(I) \]
\[ YLI=G(II)-P_{1}(K, N)/\text{DELL} \]
\[ XBS=\text{DABS}(YLI-G(II)) \]
\[ \text{IF}(XBS \leq \text{EPS}) ISL=ISL+1 \]
\[ G(II)=YLI \]

\[ 4100 \text{ CONTINUE} \]

\[ \text{DO } 4200 \text{ I}=1,\text{L} \]
\[ J=I+I \]
\[ YLI=X(J)-P_{1}(I, N)/\text{DELL} \]
\[ \text{IF}(YLI \leq 1.10) YLI=1.6 \]
\[ XBS=\text{DABS}((YLI-X(J))/X(J)) \]
\[ \text{IF}(XBS \leq \text{EPS}) ISL=ISL+1 \]
\[ X(J)=YLI \]

\[ 4200 \text{ CONTINUE} \]

\[ \text{IF}(X(NL) \leq 1.3) X(NL)=1.3 \]
\[ \text{IF}(\text{ISL} \text{LT} \text{IN}) \text{ GO TO 5} \]

C.. DELETING OF FIXED COMPOSITION PHASES

\[ 400 \text{ XX}=0. \]
\[ \text{IMIN}=0 \]

\[ \text{DO } 3100 \text{ I}=1,\text{IOPEN} \]
\[ J O=J \text{OPEN}(I) \]
\[ \text{SUM}=0. \]

\[ \text{DO } 3101 \text{ J}=I+1,\text{NL} \]
\[ \text{SUM}+A(J O, J) \times X(J) \]

\[ 3101 \text{ CONTINUE} \]
X(JO)=A(JO,N1)-SUM
IF(X(JO).GT.XX)GO TO 3100
XX=X(JO)
IMIN=JO
3100 CONTINUE

IF (ISOLU.EQ.0) RETURN
IF (IMIN.EQ.0) GO TO 1025
NUM(IMIN)=N1
GO TO 76

1025 CALL SIMFL(NL1,N,1,IP,N1,IK,IR)

IF(ISIM.EQ.1) THEN
  DELL=DELL+.5
  GO TO 75
END IF

7000 CONTINUE

RETURN
END
APPENDIX B: DATA FILES FOR PROGRAM FREZCHEM2

File DATABASE

9 - number of independent components

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<td>Mg2+</td>
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<td>SO4-2</td>
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5 - number of cations

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5 - number of anions

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4 - number of neutral species

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16 - number of solid phases

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FREZCHEM2: A Chemical Thermodynamic Model for Electrolyte Solutions at Subzero Temperatures

Mikhail V. Mironenko, Steven A. Grant, Giles M. Marion, and Ronald E. Farren

U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290

CRREL Report 97-5

Approved for public release; distribution is unlimited.
Available from NTIS, Springfield, Virginia 22161.

This report documents a Fortran version of a chemical thermodynamic model for aqueous electrolyte solutions at subzero temperatures, FREZCHEM2, which is a further development of the FREZCHEM model. The model uses thermodynamic data of Spencer-Moller-Weare that permit the calculation of chemical equilibria in the Na-K-Ca-Mg-Cl-SO_4-H_2O system between -60 and 25°C at atmospheric pressure. It applies the Gibbs energy minimization method for chemical equilibrium computation combined with Pitzer equations for activity coefficients and water activity calculation. The model includes both the freezing (melting) reaction pathway at fixed water amount and the evaporation (dilution) pathway at fixed temperature. The FREZCHEM2 model can be extended with respect to independent components, electrolyte species, and solids, and if corresponding thermodynamic data are available, the model may be used to compute chemical equilibria in any systems that include aqueous-solution and/or one-component solid phases.