FHAAC_RGB_oBL-r_plus8mmRand

Fachhochschule -Aachen, Campus Jülich

Faculties Chemistry and Biotechnology

Applied Chemistry

bachelor thesis

**Thermodynamic research on the process of salt dissolution with a double-walled container**

Changyu Liu

Matriculation number ǀ 849976

1st Inspector: Prof. Dr. J. Lauth

2nd Inspector: M.Sc. J. Kaluza

25/07/2023

### Statutory declaration

I hereby certify that I have independently prepared and written this thesis. Quotations, illustrations or diagrams that are not my own are referenced.No other sources or tools have been used.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

### Acknowledgement

This project is the final assignment to get my bachelor’s degree in applied chemistry at FH Aachen, Jülich, and was performed during my work in physical chemistry laboratory at FH Aachen, from June to August 2023.

First of all, I would like to thank my supervisor Prof. Dr. J. Lauth for the interesting subject, his support and his extraordinary commitment.

Secondly, I would like to thank M.Sc. J. Kaluza from FH Aachen for her for supervise this thesis and experimental support.

Special thanks to Lady S. Surma for her support from examination office.

Last but not least, I would like to thank my family and friends who supported me in multiple ways during my master studies.

### Table of Contents

[Statutory declaration 1](#_Toc143586030)

[Acknowledgement 3](#_Toc143586031)

[Table of Contents 4](#_Toc143586032)

[List of abbreviation 5](#_Toc143586033)

[1 Introduction 7](#_Toc143586034)

[2 Theoretical Background 8](#_Toc143586035)

[3 Experimental part 18](#_Toc143586036)

[4 Results and Discussion 28](#_Toc143586037)

[5 Summary 41](#_Toc143586038)

[6 Outlook 42](#_Toc143586039)

[Table of picture 43](#_Toc143586040)

[Table of tables 46](#_Toc143586041)

[Appendix 48](#_Toc143586042)

[References 84](#_Toc143586043)

### List of abbreviation

m: mass in grams [g]

U: voltage in Volt [V]

T: temperature in celsius degree [°C]

t: time in second [s]

I: electrical current in ampere [A]

CP: specific capacity in joule pro kelvin [J/K]

Q: heat in joule [J]

Ac: Acetate

D1, D2: the serial number of experiments in Dewar experiments

C1, C2: The serial number of the the double-walled cup experiments

Pre-period: previous period

Rel.: relativeAbstract

Double-walled coffee cup calorimeter proves highly effective in accurately determining the thermodynamic parameters of common salts. In this thesis, two calorimeters were constructed by glass and Tritan material double-walled cups. The calorimeter constant and specific heat capacity of water were successfully ascertained by both calorimeters. The experimental outcomes reaffirm the established mathematical connection between the dissolution enthalpy, lattice enthalpy, and hydration enthalpy of salts. Moreover, mathematical techniques were harnessed to rectify experiment errors, culminating in the presentation of suggested corrective measures.

### 1 Introduction

Coffee cup calorimeters have an important place in many applications and are one of the simplest tools in physical chemistry research. Traditional calorimeters, while accurate, tend to be expensive and complicated to operate, and often don´t fit well into simpler contexts such as educational settings. Over time, researchers have sought to simplify the construction of calorimeters while maintaining measurement accuracy. With the discovery of the benefits of multiple cup walls, which minimize heat loss and improve data accuracy, the double-walled coffee cup calorimeter has become increasingly popular with educators and researchers alike. This experimental apparatus is easily accessible, user-friendly and effective in determining thermodynamic parameters for common substances. Most conventional calorimeters are made of glass, which has the disadvantage of poor thermal conductivity. A novel composite material, Tritan copolyester, has emerged as a contender in this field. With attributes such as high thermal stability, robust strength, and cost effectiveness, Tritan copolyester is being used extensively in the food packaging industry. Some researchers have initiated explorations into the potential of using this material for thermodynamic measurements[1,2].

Double-walled coffee cup calorimeter prove highly effective in accurately determining the thermodynamic parameters of common salts. In this thesis, two calorimeters were constructed employing double-walled cups crafted from both glass and Tritan material. Consequently, the calorimeter constant and the specific heat capacity of water were successfully ascertained. The experimental outcomes reaffirm the established mathematical connection between the dissolution enthalpy, lattice enthalpy, and hydration enthalpy of salts. Moreover, mathematical techniques have been used to correct experimental errors, culminating in the presentation of suggested corrective measures.

### 2 Theoretical Background

The following paragraphs deal with the basics of Calorimetry, the coffee cup calorimeter and required knowledge about solution enthalpy.

#### 2.1 Coffee cup calorimeter

This chapter would introduce Coffee cup calorimeter and start with the basics of calorimetry.

Calorimetry is a vital technique in scientific research, used to quantify the heat involved in chemical or physical processes, as well as the heat transfer between various media. The simplest calorimeter can only consist of one thermometer. At present, there are many types of calorimeters commonly applied in the field of scientific research, such as differential scanning calorimeters, isothermal micro calorimeters, titration calorimeter and acceleration rate calorimeters.

The fundamental premise behind calorimetry is the assumption, that there is no heat exchange between the calorimeter and the external environment. By employing complete insulation, calorimeters effectively isolate the internal environment and contents from the external environment, ensuring that heat exchange only occurs within the calorimeter itself and associated components, such as the thermometer or magnetic stirrer. When thermal equilibrium is reached between the contents and the calorimeter system, the net heat change in the entire system, including the contents, is zero. This concept can be succinctly captured by the equation:

**-QContents = Qcalorimeter**

The mathematical signs, whether positive or negative, are only an indication of the direction of heat transfer, whether the contents have gained or lost heat.

It should be noted that in most instances, the heat absorbed by the calorimeter system is negligible. Meanwhile the calorimeter minimizes the energy exchange with the external environment. In conclusion, these characteristics allow the temperature variation recorded by the calorimeter to be regarded as an accurate reflection of the internal energy alteration within the contents during the reaction.

Calorimetric readings can be significantly affected by both the volume of the contents and the internal pressure within the calorimeter, particularly the gas form contents. To ensure precise and dependable results, it is essential to maintain a constant content volume and pressure throughout the process. A simple coffee cup calorimeter is designed for such conditions. The name "coffee cup" stems from its typical setup within an uncomplicated polymeric material cup. A coffee cup calorimeter may consist only of a plastic cup and a thermometer, perhaps with a lid.

The internal environment of the coffee cup calorimeter cannot be entirely isolated from the external. As the coffee cup cannot be completely sealed by its lid, the internal pressure of the container is inevitably equal to the moment atmospheric pressure, as well as the cup without lid. Therefore, the inside of the coffee cup can be considered as a constant pressure environment. If the substance under examination is a non-volatile liquid, and the alteration of temperature remain below the liquid's boiling point, the inside of coffee cup can also be considered as constant volume environment. Consequently, these uncomplicated calorimeters are extensively employed for measuring the heat of reaction within solutions.

图示

描述已自动生成

Figure 1: Schema of coffee-cup calorimeter.

(http://ch301.cm.utexas.edu/thermo/#thermochemistry/coffee-cup-calorim.html)

In the realm of exothermic reactions, where heat is released, the solution would absorb this energy, leading to an elevation in temperature. Conversely, endothermic reactions absorb heat from the surrounding liquid, inducing in a reduction in temperature. By meticulously documenting the temperature difference before and after the reaction, in conjunction with parameters such as the mass of the chemicals, a series of thermodynamic parameters such as molar dissolution enthalpy, molar reaction enthalpy, and specific heat capacity could be ascertained, providing valuable insights for further investigation.

#### 2.2 Double-walled container

Despite its straightforward design, the coffee cup calorimeter is not without noteworthy drawbacks. Unlike more accurate instruments, the coffee cup calorimeter is unable to eliminate heat exchange with the external environment. Various factors contribute to this, including convection between the air within the coffee cup and the external environment, as well as the escape of heat absorbed by the container`s wall to the external. This heat loss can significantly affect the accuracy of experimental results.

A simple way to overcome this is to add an extra wall surrounding the cup. . A previous research from John Young proved that an extra outer wall can reduce the heat escaping through the cup wall by 50% [3]. It is prudent to select a cup featuring a double wall with an intervening layer for the construction of a coffee cup calorimeter, probably a thermos cup. Furthermore, the material of the container selected should have minimal thermal conductivity to minimize unwanted heat The double walled cup used in this article is made from Tritan copolyester, a high molecular polymer which frequently utilized in the realm of food packaging. As this cup is not produced for chemical reactions, the intervening layer between the double wall of the cup is not vacuum. This reduces the cup's ability to insulate heat loss.

The Dewar storage, named after James Dewar, employs a comparable design, and finds extensive application in crafting

杯子里有饮料

描述已自动生成

Figure 2: Applied double-walled cup in this work.

Precise calorimeters, or the storage of refrigerants such as liquid nitrogen and liquid helium. All Dewar vessels have two or more layers of wall, and the interstitial space is kept under vacuum. This configuration imparts effective thermal insulation, demarcating the interior of the Dewar vessel from the external environment.

Another type of container used in this paper is a dual-layer glass container, with a vacuum between the inner and outer walls. Theoretically, it´s supposed to be better at insulating. Due to the complexity of Tritan materials and the uncontrollability during the production, it is not possible to simply compare the thermal conductivity of two different material containers using theoretical data. Related topics are discussed in the following chapters.

图片包含 桌子, 室内, 瓶子, 玻璃

描述已自动生成

Figure 3. Shema of a dewar storge.

#### 2.3 Enthalpy of solution

The central objective of this article is to measure enthalpy of dissolution of several inorganic salts by calorimeters constructed by two different double-walled containers. The change in enthalpy of solution is the net quantity of heat liberated or absorbed when a substance dissolves under constant pressure. This phenomenon can yield in a positive (endothermic) or negative (exothermic) enthalpy of solution. This thermodynamic parameter is often denoted to as ΔHsolv or ΔLH.

The dissolution process of a solute in a solution can be viewed as a two-step process. The first step is the bond breaking between the solute and solvent. In this step the solute and solvent molecules absorb energy and separate into their components. The second step is that these components from the new attractions between the solute and solvent and release energy to a stable state. The solution is created in this step. In a water solution, the solute and solvent could format the hydration shell system.

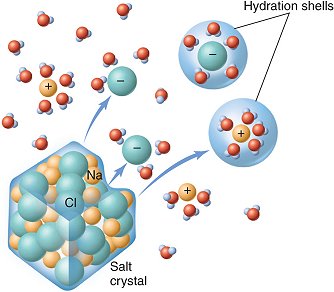
[](http://www.yellowtang.org/images/salt_dissolves_wate_c_la_784.jpg)

Figure 4: The schematic solution progress of NaCl.

In an ideal state, the intermolecular forces between solute-solute, solvent-solvent, and solute-solvent molecules are equivalent. This equilibrium results in the net enthalpy of the solution being zero. In practical situations, this enthalpy assumes an excess value, be considered as the solution enthalpy of the solute dissolved in the solvent [4].

形状

描述已自动生成Figure 5: Energy diagram for an ideal dissolving progress [4].

If the temperature of the solution decreases during the dissolution process, a negative ΔT value will be obtained. This means that the dissolution process is absorbing heat from the surrounding water and the enthalpy of solution would be positive. Conversely, the enthalpy of exothermic dissolution is negative. Within an aqueous solution, the enthalpy of dissolution can be considered as the summation of two enthalpies: the total lattice enthalpy ΔGH which is absorbed by breaking of internal bonds within the solute's lattice structure, and additionally, the total hydration enthalpy ΔHH which released though the establishment of new interactions between solute and water molecules. This intricate interplay is encapsulated in the following equation:

**ΔLH=ΔGH+ΔHH**

Formula 1: Solution enthalpy

#### 2.4 Lattice enthalpy

Lattice enthalpy serves as a measurement strength of the intensity of interaction forces among ions in an ionic solid. A higher lattice enthalpy signifies stronger interionic forces. These forces are present only when the ions are in gaseous form, because the ions separate widely from each other. For non-gaseous molecules, the intermolecular lattice enthalpy is equal to the absolute value of the lattice energy. It could be described as the enthalpy change when the salt crystal dissociates into ions. When salt is dissolved in water, the chemical bonds within the salt crystals must absorb energy to break. This energy equates to the lattice enthalpy of the ions. This dissolution process is characterized by an absorption by energy, rendering it endothermic. In other words, the energy within the salt crystal escalates, so the lattice enthalpy value is denoted as positive.

In 1918, Born and Landé proposed an equation to calculate the lattice energy [5]:

形状

中度可信度描述已自动生成

Figure 6: Born–Landé equation. Z is the charge number of the cation and anion; r is the lowest distance between ions, affected by ionic radius.

Based on this equation, the magnitude of the lattice enthalpy is chiefly influenced by two primary factors: the charge density on the ions and the ionic radius. Both the reduction of the ion radius and the increasing of the charge density of the ions would amplify the absolute value of the lattice enthalpy.

#### 2.4.1 Hydration enthalpy

When water serves as the solvent, the process of dissolution process is called hydration. At the molecular level, during this stage, salt ions engage in complex interaction with water molecules, releasing energy and the format new stable systems. The energy liberated during this process is termed as hydration enthalpy. This term is employed to describe the amount of released energy when one mole of ions undergoes hydration. During this endothermic process, salt ions lose energy and the hydration enthalpy value is denoted as negative. The interactions between salt ions and water molecules encompass hydrogen-bond, dipole-dipole, ion-induced dipole and dipole-induced dipole interactions, etc. [6]. The interplay between these interactions is extremely complicated, rendering the value of hydration enthalpy unfeasible to calculate through a straightforward formula. According to Formula 1, for a soluble salt, if its hydration energy surpasses its lattice energy, the solution enthalpy of solution will be negative. The entire dissolving process appears exothermic and increase the solution`s temperature. Conversely, if the hydration energy is less than the lattice energy, the solution enthalpy would be positive and the reaction would be endothermic and indicate the absorption of heat from the water.

图表, 气泡图

描述已自动生成

Figure : Intermolecular interactions between salt ions and water molecules [6].

#### 2.5 The calorimeter constant

As explained in chapter 2.1, during the measurement of the temperature variation by the calorimeter, a fraction of the heat is absorbed by the calorimeter system. While this heat component is relatively minor in comparison to the heat adsorbed by the solution, it's still worth to acknowledging. By treating the entire of the calorimeter system (including lid, container wall, magnetic stirrer, etc.) as an isolated entity with no heat exchange with the external environment, and presuming that any heat, which not absorbed by the solution, is absorbed by calorimeter system, it can be assumed that the entire calorimeter system has a certain heat capacity CCAL. This heat capacity is referred to calorimeter constant.

The magnitude of the calorimeter constant is related to the calorimeter apparatus itself, as well as some external factors such as the effectiveness of the seal or the room temperature. For enhanced accuracy in measurements, it's imperative to calibrate the calorimeter and measure the calorimeter constant before each assessment. This practice ensures that more accurate and reliable results are obtained.

To determine the calorimeter constant, a substance of known heat capacity is heated, often using distilled water. By comparing the heat amount gained by the water with the heat input amount delivered into water, the heat acquired by the calorimeter can be assessed.

Throughout the heating process, it is essential to control and record the heat input that from external. When an electric current of known intensity passes through the resistance wire emerged into the water, the work carried out by the current would be transformed into heat energy and which constitutes the input heat. This approach is a highly effective and reliable method of determining the calorimeter constant.

### 3 Experimental part

Based on the research of Tom Wagner [1,2] and the script of coffee cup calorimetry, 2 calorimeters were separately constructed with a glass double-walled vessel and a copolyester double-walled cup. These apparatuses were used for the following measurement:

* Measuring the calorimeter constant and the specific heat capacity of water
* Measuring the solution enthalpy of multiple salts

After each measurement, the container and thermometer both underwent a thorough rinse and left to stand for five minutes. This practice ensured that the temperature of calorimeter system temperature consistently aligned with room temperature. In the following chapter, the experimental work of this thesis is described in detail.

Table : Applied equipment list

|  |  |  |
| --- | --- | --- |
| Equipment | Productor | designation |
| Analytical balance |  |  |
| Ceramic mortar and pestle |  |  |
| Double-walled drinking cup  (Steuber culinario 500 mL) |  |  |
| *Electric thermometer* |  |  |
| *Electric water heater* |  |  |
| *Fishangel* |  |  |
| Glass beaker 60mL |  |  |
| Glass double-walled dewar container |  |  |
| Glass dropper |  |  |
| Glass watch glass |  |  |
| Hose clamp |  |  |
| magnetic stirrer (I= 2.5 cm) |  |  |
| Magnetic stirrers/heating plate |  |  |
| Measuring cylinder 50mL |  |  |
| *Multifunctional meter* |  |  |
| *power supply for heating* |  |  |
| Stopwatch |  |  |

The plastic double-walled cup used in the experiment is the same product, which used by Tom Wagner in his experiment [1]. The product information is listed here:

Table : Product information of steuber double-walled cup

|  |  |
| --- | --- |
| Art.Nr | 051477 |
| EAN.Code | 4016002027279 |
| Material | TritanTM Copolyester |
| Volume | *0.5* L |

Table : Applied chemicals list

|  |  |  |
| --- | --- | --- |
| Chemicals | Chemical  formula | Solubility at room temperature 20 °C  (g/l) |
| Calcium chloride | CaCl2 | 740 |
| Distilled water | H2O | --- |
| Potassium chloride | KCl | 355 |
| Potassium nitrate | KNO3 | 316 |
| Potassium sulfate | K2SO4 | 111 |
| Sodium acetate | CH3COONa | 365 |
| Sodium acetate  trihydrate | CH3COONa·3H2O | 613 |
| Sodium carbonate | Na₂CO₃ | 217 |
| Sodium chloride | NaCl | 317 |
| Sodium thiosulfate | Na2S2O3 | 701 |
| Sodium thiosulfate  pentahydrate | Na2S2O3·5H2O | 680 |

##### 3.1 Preparation

All inorganic salt samples used in this work are listed in Table 3. All the selected products have a high solubility in water at room temperature. However, it should be noted that these salts might absorb water from the air during the storage, potentially introducing errors in the measurement results. To mitigate that error, all samples were placed in individual glass beakers and dried in a drying cabinet at 120°C for 24 hours before the measurement, to remove any moisture content.

After the drying process, all samples were removed from the drying cabinet, sealed with plastic film, and cooled to room temperature. This process took approximately half an hour. Once cooled, all samples were ground in a mortar to ensure uniformity before being weighed and utilized for further experiments.

桌子上的玻璃瓶

低可信度描述已自动生成

Figure 8: The packaged chemicals before deliverd into the drying cabinet.

All distilled water used in the experiments was prepared one day in advance and stored at room temperature. At the start of each measurement, both the solute and solution were equilibrated to the same room temperature.

##### 3.2 The measurement of calorimeter constant and the Specific heat capacity of water

The technique employed to measure the specific heat capacity of water relies on the concept of heating water using a heating coil.

By passing a constant electrical current through a resistor, in this case a heating coil, the electrical energy undergoes conversion into thermal energy. This conversion adheres to the equation where the electrical power is equal to the heat energy produced. The resulting heat energy is than absorbed by the water. By measuring the temperature difference of the water, the specific heat capacity of water can be calculated with following formula:

Formula 2: Specific heat capacity

This experiment was carried out using both a glass double-walled vessel and a plastic double-walled cup. In the glass container, 800 grams of water were employed, accounting for approximately 80% of the container's volume. For the measurements in the plastic double-walled cup, 400 grams of distilled water was utilized. This quantity of water was sufficient to fill the cup to its brim and ensure complete submersion of the heating coil within the water.

The weighed water and a magnetic stirrer were added to the container and placed on the magnetic stirring plate. The next step is to connect the container with the thermometer, electric power, and multimeter in sequence (Figure 9).

图示

描述已自动生成

Figure 9 : The experimental scheme of measurement for specific heat capacity of water and calorimeter constant.

After assembling the experimental apparatus, the initial temperature was recorded, and the magnetic stirrer was activated at the same time. The water temperature was recorded every 10 seconds for the next 5 minutes. After the initial 5 minute period when the water temperature began to stabilize, the electrical power was switched on. A current of approximately 10 volts and 3.7 amps was directed to the heating coil. This heating phase persisted for 10 minutes. Once the heating concluded, the temperature data was recorded for a further 5 minutes, maintaining the 10-second interval for temperature readings throughout the entire process.

##### 3.3 The measurement of solution enthalpy of multiple salts

The apparatus for measuring the molar solution enthalpy of salt is roughly the same as in chapter 3.3.

厨房的摆设布局

中度可信度描述已自动生成

Figure 10: The calorimeter constructed with glass double-walled vessel.

About 5 grams of salt and 50 grams of distilled water were taken for each measurement to participate in this experiment. First, the weighed distilled water was poured into the container and a magnetic stirrer was engaged. The initial thermometer reading was noted at this moment and magnetic stirring plate was engaged. As the liquid in the container is stirred at a constant rate, the water temperature was documented at 10-second intervals. After 5 minutes, utilize a plastic funnel to incorporate the salt with precisely weighed quantity into the container. Swiftly seal the container was swiftly sealed with the lid after salt adding. The solution thermometer continued to record for a further 5 minutes. Each individual measurement was taken over 10 minutes.

桌子上摆放着黑色的机器

低可信度描述已自动生成

Figure 11: The calorimeter constructed with copolyester double walled cup.

##### 3.4 Data calibration

When it comes to calculating thermodynamic parameters such as dissolution enthalpy or reaction enthalpy, the crux lies in the acquiring of accurate temperature differences of the dissolution process. In this paper, the approach of linear extrapolation is employed to archive this goal by using the recorded dataset [7].

Linear extrapolation, known for its simplicity, represents the simplest extrapolation technique. It is well-suited for investigating data that exhibit a consistent rate of change over time. The initial step involves converting the collected temperature data into a temperature-time diagram. Following the experimental protocol, this diagram can be categorized into three distinct stages:

1. Previous period: The first phase spans from the commencement of the measurement until the salt is adding at fifth minute. During this stage, the solution's temperature gradually and evenly undergoes change due to factors such as room temperature or other external influences.
2. Reaction period: The second phase is the time from addition of salt to the point where the temperature ceases to exhibit drastic changes. This reaction could involve external heating or salt addition. Throughout this interval, the solution experiences significant temperature fluctuations.
3. Post period: The third phase following the second phase until the end of the measurement. During this interval, the solution's temperature uniformly reverts to room temperature, under the same external conditions as observed in the previous period.

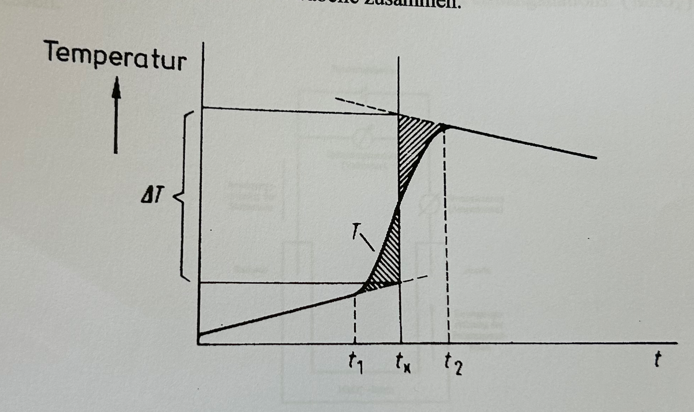


Figure : Example of temperature-time diagram

Following the application of linear regression, the data sets obtained from both previous and post period could be considered as linear. The lines of temperature change during both periods could be extrapolated. Notably, the timing that end of previous period (always at 300s) and the start of post period are denoted as time points t1 and t2 respectively. Subsequently, a perpendicular vertical line is drawn on the Y-axis at a point termed tx. This tx time point is strategically determined to fulfill the following criterion: the enclosed areas on the diagram, delineated by this vertical line, the curve from the reaction period, and the linear extrapolations from the previous or post periods, should be equivalent (shaded area in Figure 12).

From a mathematical point of view, tx is typically positioned at the midpoint between t1 and t2. The disparity between the intersections of this vertical line with the two extrapolated lines on the Y-axis provides the desired temperature difference ΔT.

In addition, there are many systematic factors that can affect the experimental results. For example, the stirring operation in the experiment provided a certain amount of heat input. The chemicals may not be ground enough before weighing. The oversized solid particles reduced the dissolution efficiency and could even lead to a lower measured temperature difference. During the addition of chemicals to the calorimeter, it was a possible that a fraction of the powdered chemicals adheres to the cup's interior walls, consequently evading incorporation into the water; The applied chemicals was possible contaminated due to the irregular using from other students. The size of the beaker utilized in the drying procedure is insufficient large, leading a portion of the chemicals were incompletely dried and remained some water content, etc.

### 4 Results and Discussion

In this chapter the results are presented sorted by the type of measurement. To provide a comprehensive overview, the temperature data are presented in tables and diagrams (in appendix). The table or diagrams of the solution temperature and time from each isothermal measurement can be found in the appendix. The data in the table is divided into three colors according to the experimental process: white for pre-period, red for reaction period and green for post-period. In particular, all time stamps for the temperature recordings have been converted to seconds for ease of calculation.

In all diagrams the temperature deferens ΔT before and after reaction has been ascertained using linear extrapolation, as outlined in section 3.6. In this chapter, the temperature estimated based on the previous period is denoted as Ta, and the temperature estimated based on the post period is denoted as Tb. When dissolution process of salt absorbs heat and causes the temperature of the system decrease, the value of ΔT could be negative. This calculated ΔT holds significant value for subsequent calculations and analysis.

The subsequent sections of this essay will delve into a thorough explication of the experimental results. This discourse will encompass a comparison with existing data from relevant literature sources. Furthermore, a critical analysis will be undertaken, to explore the underlying factors that wield influence over the results obtained.

##### 4.1 Calorimeter constant and the specific heat capacity of water

Under ideal conditions, all the work done by the electric current through the heating coil is converted into heat energy QE. This thermal energy is completely absorbed by water and other external media such as air, container wall, etc. This absorption subsequently manifests as discernible temperature change. Throughout the course of this experiment, both the electric current and voltage that traversed the heating coil remained consistently constant. Within this framework, the specific heat capacity of water is poised for computation. This calculation includes the heating time, represented as t, and can be formulated as follows:

Formula 3：The specific heat capacity of water

According to the script, the heating time was 600 seconds. During this heating process, it's noteworthy that all other external media underwent an equivalent temperature rise, mirroring the temperature changes of the water. Considering these conditions, the calorimeter constant can be calculated by the following formula.

Formula 4：Calorimeter constant

To illustrate the scenario of heating water in a Dewar container, a graphical representation in the form of Figure 4 can be constructed. This diagram integrates temperature and time as its axes. Within this visualization, both dataset from previous or post period is regressed in linear and extended. In the context of this diagram, two pivotal points Ta and Tb can be effectively computed via the linear regression formula. After this, a refined temperature difference ΔT can be accurately derived. This calculation ensures a higher level of precision in obtaining the temperature change.

Figure 13: The temperature and time curve of heating water in dewar container.

The results calculated from the experimental data are given in table 4. Examination of the experimental data reveals a remarkable similarity between the measured specific heat capacity of water and the theoretical value. This alignment underscores a conclusion: the functionality of the thermometer employed was highly effective, delivering precise and accurate temperature recordings.

Table : Measurement data from heating water

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Ta  [°C] | Tb  [°C] | ΔT  [°C] | U  [V] | I  [A] | m(H2O)  [g] | Cp(H20)  [J/g·K] | CCal  [ J/K] |
| Dewar | 20.43 | 26.501 | 6.071 | 9.77 | 3.65 | 800 | 4.405 | 3524.345 |
| Cup-1 | 19.324 | 32.518 | 13.194 | 9.84 | 3.73 | 400 | 4.173 | 1669.086 |
| Cup-2 | 20.114 | 34.617 | 14.503 | 9.98 | 3.82 | 400 | 3.943 | 1577.202 |

Furthermore, the small disparity between the experimental and theoretical value signifies an important insight. It implies that the minor heat exchange between both apparatus and the internal water has a minimal worth. As such, it can be inferred that the potential heat loss during the measurement process does not wield significant influence over the obtained results. This simple apparatus could indeed be used for thermodynamic measurements in the laboratory.

Table : Comparing the measured water specific heat capacity with the theoretical value.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Cp(H20) [ J/g·K] | Cp(H20)Θ [ J/g·K] | Deviation  [%] |
| Dewar | 4.405 | 4.181 | 5.37 |
| Cup -1 | 4.173 | 4.181 | 0.20 |
| Cup -2 | 3.943 | 4.181 | 5.69 |

According to the archives maintained in the laboratory, the calorimeter constant obtained from the same dewar container and experiment script is 3.87 kJ/K, which is very close to the measurement outcome. It's reasonable to attribute these slight disparities between the data to variations in the thermometers and the ambient room temperature.

During all the three measurements, an electric current was channeled through the heating coil, maintaining consistent intensity. The diagram (Figure 14) shows that the water temperature elevation within the double-walled cup significantly higher than dewar container, despite both setups receiving a comparable amount of heat energy from the heating coil. On the numerically side, the calorimeter constant of double-walled cup is about half of the dewar container. Synthesizing these observations, the double walled cup apparatus could absorb less heat than dewar apparatus, thereby yielding more temperature increase. This phenomenon underscores the potential superiority of the double-walled cup in terms of lower heat absorption. As a result, for subsequent experiments within this thesis, the double-walled cup should be a better equipment than the dewar container.

Figure 14: Temperature-time curve of heating water with same electric current.

##### 4.3 Dissolution enthalpy of selected salt

Table : Measured dissolution enthalpy with dewar container

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Salt | m(Salt)  [g] | m(H2O)  [g] | Ta  [°C] | Tb  [°C] | ΔT  [K] | ΔLHm  [kJ/mol] |
| NaCl | 5.029 | 51.270 | 25.49 | 24.62 | -0.875 | 2.179 |
| 5.008 | 50.055 | 25.04 | 24.66 | -0.379 | 0.926 |
| KCl | 4.949 | 50.064 | 25.28 | 23.28 | -2.003 | 6.315 |
| 4.967 | 49.713 | 23.69 | 21.97 | -1.719 | 5.361 |
| CaCl2 | 5.008 | 50.471 | 23.83 | 29.85 | 6.023 | -28.740 |
| 5.113 | 49.441 | 23.85 | 26.22 | 2.363 | -10.819 |
| Na2CO3 | 5.034 | 49.367 | 23.85 | 25.94 | 2.087 | -9.255 |
| 4.951 | 50.515 | 24.04 | 25.82 | 1.780 | -8.213 |
| K2CO3 | 4.943 | 49.911 | 24.01 | 27.00 | 2.982 | -17.756 |
| 4.954 | 49.730 | 24.21 | 25.97 | 1.764 | -10.439 |
| K2SO4 | 4.981 | 50.196 | 24.09 | 23.17 | -0.918 | 6.875 |
| 4.937 | 50.023 | 24.00 | 23.27 | -0.724 | 5.454 |
| KNO3 | 4.976 | 49.572 | 24.38 | 21.91 | -2.471 | 10.619 |
| 4.898 | 50.676 | 24.13 | 21.60 | -2.534 | 11.309 |
| NaAc | 4.960 | 49.421 | 22.98 | 25.13 | 2.147 | -7.487 |
| 4.970 | 50.075 | 22.59 | 24.35 | 1.761 | -6.210 |
| NaAc·  3H2O | 5.004 | 49.784 | 23.29 | 22.38 | -0.911 | 5.262 |
| 5.019 | 49.872 | 22.91 | 21.67 | -1.245 | 7.183 |
| Na2S2O3 | 4.924 | 49.291 | 22.98 | 23.43 | 0.445 | -3.005 |
| 4.934 | 49.834 | 22.72 | 23.21 | 0.495 | -3.373 |
| Na2S2O3·  5H2O | 4.910 | 50.086 | 22.74 | 21.35 | -1.391 | 15.026 |
| 4.984 | 49.655 | 23.25 | 21.83 | -1.418 | 14.960 |

This paper has selected 11 prevalent inorganic salts by their high solubility. The primary focus of this thesis revolves around the determination of dissolution enthalpy for these salts. The ensuing tables present the comprehensive outcomes obtained from these experiments:

Table 7: Measured dissolution enthalpy with double-walled cup.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Salt | m(Salt)  [g] | m(H2O)  [g] | Ta  [°C] | Tb  [°C] | ΔT  [K] | ΔLHm  [kJ/mol] |
| NaCl | 4.939 | 49.946 | 23.26 | 20.98 | -2.287 | 5.651 |
| 5.064 | 49.730 | 23.73 | 21.59 | -2.143 | 5.141 |
| KCl | 5.076 | 50.009 | 23.72 | 18.82 | -4.904 | 15.060 |
| 5.050 | 52.105 | 21.76 | 16.55 | -5.207 | 16.747 |
| CaCl2 | 5.148 | 50.037 | 24.66 | 31.53 | 6.875 | -31.641 |
| 5.137 | 49.820 | 22.18 | 28.17 | 5.994 | -27.526 |
| Na2CO3 | 4.996 | 50.840 | 24.77 | 28.80 | 4.033 | -18.559 |
| 5.064 | 51.681 | 22.77 | 27.83 | 5.058 | -23.344 |
| K2CO3 | 4.959 | 49.665 | 24.79 | 24.92 | 0.134 | -0.791 |
| 5.052 | 50.385 | 22.62 | 25.86 | 3.244 | -19.078 |
| K2SO4 | 5.009 | 49.608 | 24.99 | 22.13 | -2.861 | 21.067 |
| 5.701 | 55.382 | 24.39 | 23.01 | -1.378 | 9.951 |
| KNO3 | 5.046 | 49.803 | 25.68 | 20.40 | -5.276 | 22.460 |
| 5.086 | 50.516 | 23.36 | 17.87 | -5.496 | 23.547 |
| NaAc | 4.998 | 50.108 | 25.23 | 27.56 | 2.330 | -8.176 |
| 5.018 | 50.373 | 23.23 | 26.18 | 2.947 | -10.354 |
| NaAc·  3H2O | 5.027 | 49.922 | 23.15 | 21.55 | -1.602 | 9.237 |
| 4.929 | 49.584 | 22.93 | 21.32 | -1.609 | 9.398 |
| Na2S2O3 | 4.925 | 49.953 | 22.90 | 23.92 | 1.017 | -6.958 |
| 4.939 | 49.932 | 22.74 | 23.54 | 0.799 | -5.449 |
| Na2S2O3·  5H2O | 4.939 | 49.946 | 23.19 | 21.01 | -2.180 | 23.345 |
| 5.064 | 49.730 | 23.71 | 21.58 | -2.127 | 22.119 |

Once the temperature difference ΔT from the dissolution of salt has been derived by linear extrapolation, it obtains the heat of dissolution QS. Subsequently, the dissolution enthalpy of distinct salts can be accurately calculated by the formula 5:

Formula 5: Enthalpy of dissolution

##### 4.4 Data accuracy

The upcoming chapters will amalgamate the data provided in the tables and conduct comprehensive discussion. The enthalpy of dissolution data for some selected salts can be found in the literature. Comparing them with the experimental data yields the following table:

Table 8: Comparison of experimental data with literature value [8].

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Salt | ΔLHmΘ [kJ/mol] | Dewar ΔLHm [kJ/mol] | Rel.Deviation [%] | Cup ΔLHm [kJ/mol] | Rel.Deviation [%] |
| NaCl | 3.88 | 2.18 | 43.85 | 5.65 | 45.65 |
| 0.93 | 76.14 | 5.14 | 32.51 |
| KCl | 17.22 | 6.31 | 63.33 | 15.06 | 12.54 |
| 5.36 | 68.86 | 16.75 | 2.75 |
| CaCl2 | -75.26 | -28.74 | 61.81 | -31.64 | 57.96 |
| -10.82 | 85.62 | -27.53 | 63.43 |
| Na2CO3 | -23.71 | -9.26 | 60.96 | -18.56 | 21.72 |
| -8.21 | 65.36 | -23.34 | 1.55 |
| K2CO3 | -30.90 | -17.76 | 42.54 | -0.79 | 97.44 |
| -10.97 | 64.51 | -19.08 | 38.26 |
| K2SO4 | 23.80 | 6.87 | 71.12 | 21.07 | 11.48 |
| 5.45 | 77.08 | 9.95 | 58.19 |
| KNO3 | 34.89 | 10.62 | 69.57 | 22.46 | 35.63 |
| 11.31 | 67.59 | 23.55 | 32.51 |
| NaAc | -17.30 | -7.49 | 56.72 | -8.18 | 52.74 |
| -6.21 | 64.10 | -10.35 | 40.15 |

Remarkably, there is a noticeable disparity between the measured enthalpy data obtained from the dewar container and the documented data in the literature. This discrepancy is as large as70%. Although a substantial deviation persists between the double-walled cup dataset and the theoretical values, it's worth to notice that this gap is relatively smaller.

This deviation cannot be considered as systematical error.

The result was examined with Formula 5 in mathematical prospect. In comparison to similar experiments, the measured temperature difference ΔT in this experiment is notably undersized. As a direct consequence, this diminutive temperature difference directly leads to lower dissolution enthalpy. To rectify this issue, the heat absorbed by equipment QCal and the calorimeter constant CCal are added in formula 6:

Formula : Enthalpy of dissolution with calorimeter constant

The specific heat capacity of water is a constant, and each measurement applied approximately 50 g of water. Consequently, when evaluating the calculation outcomes, it should become evident, that the product of the water's specific heat *CP(H2O)* and the mass of applied water *m(H2O)* should remain relatively stable. In this context. The resulting product value stands is 209.15 J/K, which is notably smaller than in comparison to the measured calorimeter constant. Directly incorporating the calorimeter constants into the calculations will result the outcomes in the substantial amplification, and more questionable.

From the supplementary literature, it is established that the calorimeter constant should ideally be maintained at 24 J/K for such measurement with polymeric foam cup [3]. The variance between the suggested and observed calorimeter constants may be attributed to the dissimilar quantities of utilized water. During the measurement of calorimeter constant, the two different containers each held 800 mL and 400 mL liquid, and both almost fill the container. However, in dissolution enthalpy measurement, there was only 50 mL of liquid was used. In scenarios where the contact of the air with the liquid level in the container remains unaltered, this dissimilarity in liquid volume leads to a significantly reducing, which the heat exchange area between the liquid and the internal container walls during the measurement, as well as the calorimeter itself. Consequently, the calorimeter constant value is considerable reduced under these circumstances.

Unfortunately, the available equipment in the laboratory poses a constraint in this context: The heating coils are insufficiently long to be immersed in 50 mL of the liquid for both containers. To guarantee the complete submersion of the heating coil, it requires multiple amounts of water and chemicals. It is therefore not possible to measure an usable calorimeter constant with the existing laboratory equipment.

桌子上的玻璃杯

描述已自动生成

Figure 15: Heating coil`s length is not enough for 50 mL liquid in double-walled cup.

##### 4.5 Effect from radius and charge density of salt ion.

Despite the substantial disparity between the measured data and the theoretical values, some discernible patterns and regularities can still be found. In the upcoming chapters, the measured data that come close to the theoretical value will be chosen for analysis and discussion.

Table : Measured data of selected chlorides.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Salt | Ta [°C] | Tb [°C] | ΔT [°C] | ΔLHm [kJ/mol] | ΔLHmΘ [kJ/mol] | Rel.Deviation [%] | Container |
| NaCl | 23.72 | 21.59 | -2.14 | 5.141 | 3.88 | 32.51 | Cup |
| KCl | 21.75 | 16.55 | -5.21 | 16.747 | 17.22 | 2.75 | Cup |
| CaCl2 | 24.65 | 31.53 | 6.88 | -31.641 | -75.26 | 57.96 | Cup |

Sodium chloride, potassium chloride and calcium chloride are common inorganic chloride. Upon comparing the molar dissolution enthalpies of these three salts, it can be observed that sodium chloride and potassium chloride are endothermic after dissolution, but calcium chloride is exothermic. Furthermore, upon the absolute values of the dissolution enthalpies, the heat change range from the dissolution of potassium chloride is larger than sodium chloride, and smaller than that of calcium chloride. These observed outcomes align well with the theoretical value.

The ionic radius of sodium is smaller than that of potassium. From Born–Landé equation, this variation results in decrease of lattice enthalpy of chloride [9]. On the other hand, this also leads to a more substantial decrease in the hydration enthalpy of the metal cation [10]. Some theoretical value of lattice enthalpy and hydration enthalpy of distinct salt and ion could be found in table 10 as reference.

Table : Literature data of Lattice enthalpy and hydration enthalpy [11–13].

|  |  |  |  |
| --- | --- | --- | --- |
| Salt | ΔGHm [kJ/mol] | Ion | ΔHHm [kJ/mol] |
| NaCl | 786.0 | **CO32-** | -1389.1 |
| KCl | 710.0 | **SO42-** | -1016.7 |
| CaCl2 | 2159.0 | **NO3-** | -314 |
| Na2CO3 | 2030.0 | **Cl-** | -351 |
| K2CO3 | 1858.0 | **Na+** | -422.6 |
| K2SO4 | 1796.0 | **K+** | -338.9 |
| KNO3 | 674.2 | **Ca2+** | -1615 |

This rationale can likewise account for the correlation between the dissolution enthalpies of sodium carbonate and potassium carbonate: these two salts share an identical carbonate anion, differing solely in the type of metal cation (Table 10).

Table : Measured data of sodium carbonate and potassium carbonate.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Salt | Ta [°C] | Tb [°C] | ΔT [°C] | ΔLHm [kJ/mol] | ΔLHmΘ [kJ/mol] | Rel.Deviation [%] | Container |
| NaCO3 | 22.771 | 27.829 | 5.058 | -23.3435 | -23.71 | 1.55 | Cup |
| KCO3 | 22.618 | 25.862 | 3.244 | -19.0785 | -30.9 | 38.26 | Cup |

Comparing potassium and calcium ions within the same time, apart from the increase of ionic radius, an additional distinct factor is the charge density of calcium, which doubled from potassium. Consequently, this discrepancy of charge density leads to a notable escalation in the absolute values of both the lattice enthalpy of the calcium chloride and the hydration enthalpy of the calcium ion. These substantial shifts in energy values underline the influential role played of charge density in dictating the energetics of chemical processes.

The data presented in the table 10 confirm this view. During the dissolution of calcium chloride, the produced calcium cation and chloride anion engender the hydration layer with surrounding water and release energy, which equal to their hydration enthalpy. The released energy is surpassed another amount of energy, which absorbed during the breaking of ionic bonds within the calcium chloride molecule. This latter energy corresponds to the lattice enthalpy of calcium chloride. The difference between the released and absorbed energies causes the dissolution of calcium chloride exothermic.

##### 4.6 Effect of contented Crystal water

Another regularity becomes discernible during the measurement of the solution enthalpy of salts that encompass crystallized water.

Table : Measured data of sodium salts and its hydrate.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Salt | Ta [°C] | Tb [°C] | ΔT [°C] | ΔLHm [kJ/mol] | Container |
| NaAc | 23.232 | 26.179 | 2.947 | -10.3539 | Cup |
| NaAc·3H2O | 22.93 | 21.32 | -1.609 | 9.398 | Cup |
| Na2S2O3 | 22.90005 | 23.917 | 1.01695 | -6.95824 | Cup |
| Na2S2O3·5H2O | 23.185 | 21.005 | -2.18 | 23.34467 | Cup |

The solution enthalpy of sodium acetate and sodium thiosulfate has a negative value, signifying the heat release during the dissolving process. Conversely, their hydrates absorb heat in dissolution, lead to temperature decrease in the solution. The calculated solution enthalpy of these hydrates is also positive.

This phenomenon can still be elucidated through the interplay between the lattice and hydration enthalpy of salt ions. In instances devoid of water of crystallization, both salt ions exhibit a lattice enthalpy exceeding their hydration enthalpy. The solution enthalpy of each salt assumes a numerically positive value, indicative of an exothermic process during dissolution.

This stems from the fact that the ions within the crystal of salt hydrates are already predominantly hydrated. The dissolution process mainly involves breaking the ionic lattices of these salts, which is restricted [1]. In this situation, the magnitude of the lattice enthalpy of hydrated salt is significantly smaller than to its hydration enthalpy. This contrast in values leads to a reversal in the direction of the thermal reaction during the dissolving process.

Figure ：Time-Temperature curve diagram of NaAc and NaAc·3H2O in plastic cup.

### 5 Summary

This thesis offers a comprehensive overview of coffee cup calorimetry. Two calorimeters founded on the double-wall model were constructed and employed in various measurements. The initial determination of the calorimeter constant for each device was accomplished. The outcomes demonstrated that the plastic cup exhibited lower heat absorption compared to the glass vessel, thereby showcasing its advantage. Subsequently, the specific heat capacity of water was accurately quantified by both containers. The obtained results closely aligned with theoretical values, thereby affirming the efficacy of the experimental setup.

Furthermore, correlations between solution enthalpy, lattice enthalpy, and hydration enthalpy were established through the study of 11 distinct salt. As anticipated, both ion radius and charge density exerted an impact on solution enthalpy, along with the content of crystallized water. These findings were corroborated by prior research.

However, the collected data from multiple measurements unveiled challenges and limitations inherent to this measurement approach. Notably, the measured results exhibited substantial deviations from literature values. The methodology for determining the calorimeter constant could be refined, particularly concerning the volume of liquid employed.

### 6 Outlook

This thesis underscores the substantial potential of the double-walled coffee cup calorimeter in the realm of thermal investigation. To harness its advantages of simplicity in construction and ease of operation, there is more space for refining and standardizing the measurement procedure. One avenue for optimization involves exploring the feasibility of extending the measurement times and increasing the quantities of solution and solute, which holds promise for improving experimental outcomes.

Incorporating more advanced calorimeters like Differential Scanning Calorimeters (DSC) as controls can provide valuable insights and aid in refining experiments. This integration result could lead to more accurate and intuitive correlations between solution enthalpy, lattice enthalpy, and hydration enthalpy.

While acknowledging that the coffee cup calorimeter remains a lower-tier alternative to conventional calorimeters, it's important to recognize that certain reactions producing significant heat changes may still be unsafe to measure using this method. Nonetheless, for educational and research purposes, particularly in school settings, the coffee cup calorimeter remains a valuable and commendable choice.

### Table of picture

[Figure 1: Schema of coffee-cup calorimeter. 10](#_Toc143585855)

[Figure 2: Applied double-walled cup in this work. 11](#_Toc143585856)

[Figure 3. Shema of a dewar storge. 12](#_Toc143585857)

[Figure 4: The schematic solution progress of NaCl. 13](#_Toc143585858)

[Figure 5: Energy diagram for an ideal dissolving progress [4]. 14](#_Toc143585859)

[Figure 6: Born–Landé equation. Z is the charge number of the cation and anion; r is the lowest distance between ions, affected by ionic radius. 15](#_Toc143585860)

[Figure 7: Intermolecular interactions between salt ions and water molecules [6]. 16](#_Toc143585861)

[Figure 8: The packaged chemicals before deliverd into the drying cabinet. 20](#_Toc143585862)

[Figure 9 : The experimental scheme of measurement for specific heat capacity of water and calorimeter constant. 22](#_Toc143585863)

[Figure 10: The calorimeter constructed with glass double-walled vessel. 23](#_Toc143585864)

[Figure 11: The calorimeter constructed with copolyester double walled cup. 24](#_Toc143585865)

[Figure 12: Example of temperature-time diagram 26](#_Toc143585866)

[Figure 13: The temperature and time curve of heating water in dewar container. 30](#_Toc143585867)

[Figure 14: Temperature-time curve of heating water with same electric current. 32](#_Toc143585868)

[Figure 15: Heating coil`s length is not enough for 50 mL liquid in double-walled cup. 37](#_Toc143585869)

[Figure 16：Time-Temperature curve diagram of NaAc and NaAc·3H2O in plastic cup. 40](#_Toc143585870)

[Figure 17: Time-Temperature diagrams of heating water in cup. 49](#_Toc143585871)

[Figure 18: Time-temperature diagrams of NaCl in dewar vessel. 51](#_Toc143585872)

[Figure 19: Time-temperature diagrams of NaCl in cup. 52](#_Toc143585873)

[Figure 20: Time-temperature diagrams of KCl in dewar vessel. 54](#_Toc143585874)

[Figure 21: Time-temperature diagrams of KCl in cup. 55](#_Toc143585875)

[Figure 22: Time-temperature diagrams of CaCL2 in dewar vessel. 57](#_Toc143585876)

[Figure 23: Time-temperature diagrams of CaCl2 in cup. 58](#_Toc143585877)

[Figure 24: Time-temperature diagrams of Na2CO3 in dewar vessel. 60](#_Toc143585878)

[Figure 25: Time-temperature diagrams of Na2CO3 in cup. 61](#_Toc143585879)

[Figure 26: Time-temperature diagrams of K2CO3 in dewar vessel. 63](#_Toc143585880)

[Figure 27: Time-temperature diagrams of K2CO3 in cup. 64](#_Toc143585881)

[Figure 28: Time-temperature diagrams of K2SO4 in dewar vessel. 66](#_Toc143585882)

[Figure 29: Time-temperature diagrams of K2SO4 in cup. 67](#_Toc143585883)

[Figure 30: Time-temperature diagrams of KNO3 in dewar vessel. 69](#_Toc143585884)

[Figure 31: Time-temperature diagrams of KNO3 in cup. 70](#_Toc143585885)

[Figure 32: Time-temperature diagrams of NaAC in dewar vessel 72](#_Toc143585886)

[Figure 33: Time-temperature diagrams of NaAC in cup. 73](#_Toc143585887)

[Figure 34：Time-temperature diagrams of NaAC·3H2O in dewar vessel. 75](#_Toc143585888)

[Figure 35: Time-temperature diagrams of NaAC·3H2O in cup. 76](#_Toc143585889)

[Figure 36: Time-temperature diagrams of Na2S2O3 in dewar vessel. 78](#_Toc143585890)

[Figure 37: Time-temperature diagrams of Na2S2O3 in cup. 79](#_Toc143585891)

[Figure 38: Time-temperature diagrams of Na2S2O3·5H2O in dewar vessel. 81](#_Toc143585892)

[Figure 39: Time-temperature diagrams of Na2S2O3·5H2O in cup. 82](#_Toc143585893)

### Table of tables

[Table 1: Applied equipment list 18](#_Toc143585894)

[Table 2: Product information of steuber double-walled cup 19](#_Toc143585895)

[Table 3: Applied chemicals list 19](#_Toc143585896)

[Table 4: Measurement data from heating water 30](#_Toc143585897)

[Table 5: Comparing the measured water specific heat capacity with the theoretical value. 31](#_Toc143585898)

[Table 6: Measured dissolution enthalpy with dewar container 33](#_Toc143585899)

[Table 7: Measured dissolution enthalpy with double-walled cup. 34](#_Toc143585900)

[Table 8: Comparison of experimental data with literature value [8]. 35](#_Toc143585901)

[Table 9: Measured data of selected chlorides. 37](#_Toc143585902)

[Table 10: Literature data of Lattice enthalpy and hydration enthalpy [11–13]. 38](#_Toc143585903)

[Table 11: Measured data of sodium carbonate and potassium carbonate. 38](#_Toc143585904)

[Table 12: Measured data of sodium salts and its hydrate. 39](#_Toc143585905)

[Table 13: Measurement data of heating water in both dewar container and double-walled cup. 48](#_Toc143585906)

[Table 14: Measured dataset of NaCl 51](#_Toc143585907)

[Table 15: Measured dataset of KCl 54](#_Toc143585908)

[Table 16: Measured dataset of CaCl2. 57](#_Toc143585909)

[Table 17: Measured dataset of Na2CO3. 60](#_Toc143585910)

[Table 18: Measured dataset of K2CO3. 63](#_Toc143585911)

[Table 19: Measured dataset of K2SO4 66](#_Toc143585912)

[Table 20: Measured dataset of KNO3 69](#_Toc143585913)

[Table 21: Measured dataset of NaAc. 72](#_Toc143585914)

[Table 22: Measured dataset of NaAC·3H2O 75](#_Toc143585915)

[Table 23: Measured dataset of Na2SO3. 78](#_Toc143585916)

[Table 24: Measured dataset of Na2SO3·5H2O. 81](#_Toc143585917)

### Appendix

In this appendix the dataset and its temperature-time diagram are listed.

Table 13: Measurement data of heating water in both dewar container and double-walled cup.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Dewar | Cup-1 | Cup-2 |
| **Time [s]** | **Temperature [°C]** | **Temperature [°C]** | **Temperature [°C]** |
| 0 | 20.37 | 18.96 | 19.81 |
| 10 | 20.37 | 18.97 | 19.81 |
| 20 | 20.38 | 18.97 | 19.82 |
| 30 | 20.38 | 18.98 | 19.83 |
| 40 | 20.38 | 18.99 | 19.83 |
| 50 | 20.38 | 19.00 | 19.84 |
| 60 | 20.38 | 19.00 | 19.85 |
| 70 | 20.38 | 19.01 | 19.85 |
| 80 | 20.38 | 19.02 | 19.86 |
| 90 | 20.38 | 19.02 | 19.86 |
| 100 | 20.38 | 19.03 | 19.87 |
| 110 | 20.38 | 19.04 | 19.87 |
| 120 | 20.38 | 19.04 | 19.88 |
| 130 | 20.38 | 19.05 | 19.89 |
| 140 | 20.38 | 19.06 | 19.89 |
| 150 | 20.39 | 19.06 | 19.90 |
| 160 | 20.39 | 19.07 | 19.90 |
| 170 | 20.40 | 19.07 | 19.91 |
| 180 | 20.40 | 19.08 | 19.91 |
| 190 | 20.40 | 19.09 | 19.92 |
| 200 | 20.40 | 19.10 | 19.92 |
| 210 | 20.40 | 19.10 | 19.93 |
| 220 | 20.40 | 19.11 | 19.93 |
| 230 | 20.40 | 19.11 | 19.94 |
| 240 | 20.40 | 19.12 | 19.94 |
| 250 | 20.41 | 19.13 | 19.94 |
| 260 | 20.41 | 19.13 | 19.95 |
| 270 | 20.41 | 19.14 | 19.95 |
| 280 | 20.41 | 19.14 | 19.95 |
| 290 | 20.41 | 19.15 | 19.96 |
| 300 | 20.41 | 19.15 | 19.97 |
| 310 | 20.45 | 19.27 | 20.05 |
| 320 | 20.52 | 19.51 | 20.32 |
| 330 | 20.63 | 19.74 | 20.50 |
| 340 | 20.72 | 19.95 | 20.74 |
| 350 | 20.88 | 20.18 | 20.96 |
| 360 | 20.96 | 20.34 | 21.18 |
| 370 | 21.02 | 20.53 | 21.41 |
| 380 | 21.13 | 20.72 | 21.62 |
| 390 | 21.23 | 20.90 | 21.80 |
| 400 | 21.33 | 21.15 | 22.01 |
| 410 | 21.42 | 21.32 | 22.23 |
| 420 | 21.53 | 21.50 | 22.48 |
| 430 | 21.63 | 21.69 | 22.69 |
| 440 | 21.73 | 21.90 | 22.90 |
| 450 | 21.83 | 22.06 | 23.12 |
| 460 | 21.92 | 22.25 | 23.32 |
| 470 | 22.02 | 22.47 | 23.53 |
| 480 | 22.13 | 22.66 | 23.74 |
| 490 | 22.23 | 22.86 | 23.95 |
| 500 | 22.32 | 23.05 | 24.16 |
| 510 | 22.42 | 23.23 | 24.40 |
| 520 | 22.52 | 23.43 | 24.61 |
| 530 | 22.61 | 23.61 | 24.80 |
| 540 | 22.71 | 23.80 | 24.99 |
| 550 | 22.82 | 23.96 | 25.20 |
| 560 | 22.92 | 24.16 | 25.41 |
| 570 | 23.00 | 24.33 | 25.63 |
| 580 | 23.12 | 24.57 | 25.84 |
| 590 | 23.20 | 24.76 | 26.06 |
| 600 | 23.31 | 24.96 | 26.27 |
| 610 | 23.41 | 25.11 | 26.45 |
| 620 | 23.50 | 25.31 | 26.64 |
| 630 | 23.60 | 25.52 | 26.85 |
| 640 | 23.70 | 25.69 | 27.04 |
| 650 | 23.80 | 25.86 | 27.27 |
| 660 | 23.90 | 26.10 | 27.46 |
| 670 | 24.00 | 26.27 | 27.66 |
| 680 | 24.10 | 26.45 | 27.87 |
| 690 | 24.19 | 26.62 | 28.10 |
| 700 | 24.30 | 26.82 | 28.30 |
| 710 | 24.40 | 27.00 | 28.50 |
| 720 | 24.49 | 27.20 | 28.70 |
| 730 | 24.59 | 27.39 | 28.91 |
| 740 | 24.69 | 27.60 | 29.09 |
| 750 | 24.79 | 27.77 | 29.32 |
| 760 | 24.90 | 27.94 | 29.51 |
| 770 | 24.98 | 28.14 | 29.70 |
| 780 | 25.09 | 28.34 | 29.89 |
| 790 | 25.18 | 28.49 | 30.10 |
| 800 | 25.28 | 28.67 | 30.31 |
| 810 | 25.39 | 28.87 | 30.51 |
| 820 | 25.49 | 28.97 | 30.71 |
| 830 | 25.58 | 29.27 | 30.92 |
| 840 | 25.67 | 29.42 | 31.11 |
| 850 | 25.78 | 29.62 | 31.31 |
| 860 | 25.87 | 29.81 | 31.51 |
| 870 | 25.97 | 29.97 | 31.70 |
| 880 | 26.07 | 30.14 | 31.92 |
| 890 | 26.17 | 30.35 | 32.09 |
| 900 | 26.26 | 30.52 | 32.29 |
| 910 | 26.41 | 30.67 | 32.44 |
| 920 | 26.42 | 30.60 | 32.40 |
| 930 | 26.41 | 30.53 | 32.36 |
| 940 | 26.41 | 30.50 | 32.34 |
| 950 | 26.41 | 30.48 | 32.32 |
| 960 | 26.41 | 30.47 | 32.31 |
| 970 | 26.41 | 30.46 | 32.29 |
| 980 | 26.40 | 30.44 | 32.28 |
| 990 | 26.40 | 30.43 | 32.26 |
| 1000 | 26.39 | 30.42 | 32.25 |
| 1010 | 26.39 | 30.41 | 32.23 |
| 1020 | 26.39 | 30.39 | 32.22 |
| 1030 | 26.38 | 30.38 | 32.20 |
| 1040 | 26.38 | 30.37 | 32.19 |
| 1050 | 26.38 | 30.36 | 32.18 |
| 1060 | 26.37 | 30.35 | 32.16 |
| 1070 | 26.37 | 30.33 | 32.15 |
| 1080 | 26.37 | 30.32 | 32.13 |
| 1090 | 26.37 | 30.31 | 32.12 |
| 1100 | 26.36 | 30.30 | 32.11 |
| 1110 | 26.36 | 30.29 | 32.09 |
| 1120 | 26.36 | 30.28 | 32.08 |
| 1130 | 26.36 | 30.27 | 32.07 |
| 1140 | 26.35 | 30.26 | 32.06 |
| 1150 | 26.35 | 30.25 | 32.04 |
| 1160 | 26.35 | 30.25 | 32.03 |
| 1170 | 26.34 | 30.23 | 32.01 |
| 1180 | 26.34 | 30.22 | 32.00 |
| 1190 | 26.34 | 30.21 | 31.99 |
| 1200 | 26.34 | 30.20 | 31.98 |

Figure : Time-Temperature diagrams of heating water in cup.

Table : Measured dataset of NaCl

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 24.40 | 0 | 24.74 | 0 | 22.59 | 0 | 23.57 |
| 10 | 24.52 | 10 | 24.76 | 10 | 22.65 | 10 | 23.57 |
| 20 | 24.62 | 20 | 24.77 | 20 | 22.70 | 20 | 23.57 |
| 30 | 24.68 | 30 | 24.78 | 30 | 22.74 | 30 | 23.58 |
| 40 | 24.73 | 40 | 24.79 | 40 | 22.78 | 40 | 23.58 |
| 50 | 24.77 | 50 | 24.80 | 50 | 22.80 | 50 | 23.58 |
| 60 | 24.82 | 60 | 24.81 | 60 | 22.83 | 60 | 23.59 |
| 70 | 24.87 | 70 | 24.82 | 70 | 22.85 | 70 | 23.59 |
| 80 | 24.92 | 80 | 24.83 | 80 | 22.87 | 80 | 23.60 |
| 90 | 24.97 | 90 | 24.84 | 90 | 22.89 | 90 | 23.60 |
| 100 | 25.01 | 100 | 24.85 | 100 | 22.91 | 100 | 23.60 |
| 110 | 25.05 | 110 | 24.85 | 110 | 22.92 | 110 | 23.61 |
| 120 | 25.09 | 120 | 24.86 | 120 | 22.94 | 120 | 23.61 |
| 130 | 25.12 | 130 | 24.87 | 130 | 22.95 | 130 | 23.62 |
| 140 | 25.15 | 140 | 24.87 | 140 | 22.97 | 140 | 23.62 |
| 150 | 25.18 | 150 | 24.89 | 150 | 22.98 | 150 | 23.62 |
| 160 | 25.20 | 160 | 24.90 | 160 | 22.99 | 160 | 23.63 |
| 170 | 25.23 | 170 | 24.90 | 170 | 23.00 | 170 | 23.63 |
| 180 | 25.25 | 180 | 24.91 | 180 | 23.01 | 180 | 23.64 |
| 190 | 25.27 | 190 | 24.92 | 190 | 23.03 | 190 | 23.64 |
| 200 | 25.28 | 200 | 24.92 | 200 | 23.04 | 200 | 23.64 |
| 210 | 25.30 | 210 | 24.93 | 210 | 23.05 | 210 | 23.65 |
| 220 | 25.31 | 220 | 24.94 | 220 | 23.06 | 220 | 23.65 |
| 230 | 25.33 | 230 | 24.95 | 230 | 23.06 | 230 | 23.65 |
| 240 | 25.34 | 240 | 24.96 | 240 | 23.07 | 240 | 23.66 |
| 250 | 25.35 | 250 | 24.96 | 250 | 23.08 | 250 | 23.66 |
| 260 | 25.36 | 260 | 24.97 | 260 | 23.09 | 260 | 23.66 |
| 270 | 25.37 | 270 | 24.97 | 270 | 23.10 | 270 | 23.67 |
| 280 | 25.38 | 280 | 24.98 | 280 | 23.10 | 280 | 23.67 |
| 290 | 25.39 | 290 | 24.99 | 290 | 23.11 | 290 | 23.67 |
| 300 | 25.41 | 300 | 24.99 | 300 | 23.12 | 300 | 23.67 |
| 310 | 25.32 | 310 | 24.93 | 310 | 23.03 | 310 | 23.52 |
| 320 | 25.25 | 320 | 24.90 | 320 | 22.85 | 320 | 23.08 |
| 330 | 25.18 | 330 | 24.85 | 330 | 22.63 | 330 | 22.72 |
| 340 | 25.10 | 340 | 24.80 | 340 | 22.41 | 340 | 22.49 |
| 350 | 25.03 | 350 | 24.76 | 350 | 22.23 | 350 | 22.32 |
| 360 | 24.98 | 360 | 24.72 | 360 | 22.06 | 360 | 22.19 |
| 370 | 24.93 | 370 | 24.69 | 370 | 21.90 | 370 | 22.08 |
| 380 | 24.89 | 380 | 24.67 | 380 | 21.77 | 380 | 21.99 |
| 390 | 24.86 | 390 | 24.65 | 390 | 21.65 | 390 | 21.92 |
| 400 | 24.82 | 400 | 24.63 | 400 | 21.55 | 400 | 21.86 |
| 410 | 24.79 | 410 | 24.62 | 410 | 21.46 | 410 | 21.81 |
| 420 | 24.78 | 420 | 24.61 | 420 | 21.37 | 420 | 21.76 |
| 430 | 24.76 | 430 | 24.60 | 430 | 21.29 | 430 | 21.73 |
| 440 | 24.74 | 440 | 24.59 | 440 | 21.23 | 440 | 21.69 |
| 450 | 24.73 | 450 | 24.58 | 450 | 21.16 | 450 | 21.66 |
| 460 | 24.73 | 460 | 24.57 | 460 | 21.11 | 460 | 21.64 |
| 470 | 24.73 | 470 | 24.56 | 470 | 21.06 | 470 | 21.62 |
| 480 | 24.73 | 480 | 24.56 | 480 | 21.01 | 480 | 21.60 |
| 490 | 24.74 | 490 | 24.55 | 490 | 20.97 | 490 | 21.59 |
| 500 | 24.75 | 500 | 24.54 | 500 | 20.94 | 500 | 21.57 |
| 510 | 24.75 | 510 | 24.53 | 510 | 20.91 | 510 | 21.56 |
| 520 | 24.76 | 520 | 24.53 | 520 | 20.89 | 520 | 21.55 |
| 530 | 24.77 | 530 | 24.53 | 530 | 20.86 | 530 | 21.55 |
| 540 | 24.79 | 540 | 24.53 | 540 | 20.85 | 540 | 21.55 |
| 550 | 24.80 | 550 | 24.53 | 550 | 20.83 | 550 | 21.54 |
| 560 | 24.81 | 560 | 24.53 | 560 | 20.82 | 560 | 21.54 |
| 570 | 24.82 | 570 | 24.53 | 570 | 20.81 | 570 | 21.54 |
| 580 | 24.83 | 580 | 24.53 | 580 | 20.80 | 580 | 21.54 |
| 590 | 24.84 | 590 | 24.53 | 590 | 20.80 | 590 | 21.54 |
| 600 | 24.85 | 600 | 24.53 | 600 | 20.79 | 600 | 21.54 |

Figure : Time-temperature diagrams of NaCl in dewar vessel.

Figure : Time-temperature diagrams of NaCl in cup.

Table : Measured dataset of KCl

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 25.02 | 0 | 23.31 | 0 | 23.34 | 0 | 21.44 |
| 10 | 25.04 | 10 | 23.32 | 10 | 23.40 | 10 | 21.47 |
| 20 | 25.05 | 20 | 23.31 | 20 | 23.44 | 20 | 21.51 |
| 30 | 25.05 | 30 | 23.31 | 30 | 23.46 | 30 | 21.52 |
| 40 | 25.06 | 40 | 23.32 | 40 | 23.47 | 40 | 21.54 |
| 50 | 25.07 | 50 | 23.34 | 50 | 23.49 | 50 | 21.55 |
| 60 | 25.08 | 60 | 23.35 | 60 | 23.50 | 60 | 21.56 |
| 70 | 25.08 | 70 | 23.36 | 70 | 23.51 | 70 | 21.57 |
| 80 | 25.09 | 80 | 23.38 | 80 | 23.52 | 80 | 21.58 |
| 90 | 25.10 | 90 | 23.39 | 90 | 23.53 | 90 | 21.58 |
| 100 | 25.10 | 100 | 23.40 | 100 | 23.54 | 100 | 21.58 |
| 110 | 25.11 | 110 | 23.41 | 110 | 23.55 | 110 | 21.59 |
| 120 | 25.11 | 120 | 23.42 | 120 | 23.55 | 120 | 21.59 |
| 130 | 25.12 | 130 | 23.43 | 130 | 23.56 | 130 | 21.59 |
| 140 | 25.13 | 140 | 23.45 | 140 | 23.57 | 140 | 21.60 |
| 150 | 25.13 | 150 | 23.47 | 150 | 23.57 | 150 | 21.61 |
| 160 | 25.14 | 160 | 23.48 | 160 | 23.58 | 160 | 21.61 |
| 170 | 25.15 | 170 | 23.48 | 170 | 23.59 | 170 | 21.62 |
| 180 | 25.15 | 180 | 23.49 | 180 | 23.59 | 180 | 21.62 |
| 190 | 25.15 | 190 | 23.50 | 190 | 23.60 | 190 | 21.63 |
| 200 | 25.16 | 200 | 23.51 | 200 | 23.60 | 200 | 21.64 |
| 210 | 25.16 | 210 | 23.51 | 210 | 23.61 | 210 | 21.64 |
| 220 | 25.17 | 220 | 23.52 | 220 | 23.61 | 220 | 21.65 |
| 230 | 25.17 | 230 | 23.52 | 230 | 23.62 | 230 | 21.65 |
| 240 | 25.17 | 240 | 23.53 | 240 | 23.62 | 240 | 21.66 |
| 250 | 25.18 | 250 | 23.53 | 250 | 23.63 | 250 | 21.66 |
| 260 | 25.18 | 260 | 23.54 | 260 | 23.63 | 260 | 21.67 |
| 270 | 25.19 | 270 | 23.55 | 270 | 23.64 | 270 | 21.67 |
| 280 | 25.19 | 280 | 23.55 | 280 | 23.64 | 280 | 21.68 |
| 290 | 25.20 | 290 | 23.56 | 290 | 23.64 | 290 | 21.68 |
| 300 | 25.20 | 300 | 23.56 | 300 | 23.65 | 300 | 21.69 |
| 310 | 24.59 | 310 | 23.34 | 310 | 23.06 | 310 | 19.79 |
| 320 | 24.36 | 320 | 23.10 | 320 | 21.88 | 320 | 18.09 |
| 330 | 24.18 | 330 | 22.85 | 330 | 21.33 | 330 | 18.36 |
| 340 | 24.02 | 340 | 22.67 | 340 | 20.86 | 340 | 17.96 |
| 350 | 23.90 | 350 | 22.53 | 350 | 20.45 | 350 | 17.77 |
| 360 | 23.80 | 360 | 22.42 | 360 | 20.17 | 360 | 17.73 |
| 370 | 23.71 | 370 | 22.33 | 370 | 20.01 | 370 | 17.62 |
| 380 | 23.64 | 380 | 22.25 | 380 | 19.91 | 380 | 17.62 |
| 390 | 23.58 | 390 | 22.18 | 390 | 19.85 | 390 | 17.65 |
| 400 | 23.54 | 400 | 22.13 | 400 | 19.81 | 400 | 17.64 |
| 410 | 23.50 | 410 | 22.09 | 410 | 19.79 | 410 | 17.62 |
| 420 | 23.46 | 420 | 22.06 | 420 | 19.79 | 420 | 17.61 |
| 430 | 23.43 | 430 | 22.02 | 430 | 19.78 | 430 | 17.60 |
| 440 | 23.40 | 440 | 21.99 | 440 | 19.78 | 440 | 17.61 |
| 450 | 23.38 | 450 | 21.97 | 450 | 19.78 | 450 | 17.61 |
| 460 | 23.35 | 460 | 21.95 | 460 | 19.79 | 460 | 17.62 |
| 470 | 23.33 | 470 | 21.93 | 470 | 19.80 | 470 | 17.64 |
| 480 | 23.31 | 480 | 21.91 | 480 | 19.82 | 480 | 17.65 |
| 490 | 23.29 | 490 | 21.90 | 490 | 19.83 | 490 | 17.66 |
| 500 | 23.28 | 500 | 21.88 | 500 | 19.83 | 500 | 17.67 |
| 510 | 23.26 | 510 | 21.87 | 510 | 19.85 | 510 | 17.69 |
| 520 | 23.25 | 520 | 21.86 | 520 | 19.86 | 520 | 17.70 |
| 530 | 23.23 | 530 | 21.85 | 530 | 19.88 | 530 | 17.71 |
| 540 | 23.23 | 540 | 21.84 | 540 | 19.89 | 540 | 17.73 |
| 550 | 23.23 | 550 | 21.83 | 550 | 19.90 | 550 | 17.75 |
| 560 | 23.22 | 560 | 21.82 | 560 | 19.91 | 560 | 17.76 |
| 570 | 23.21 | 570 | 21.82 | 570 | 19.92 | 570 | 17.77 |
| 580 | 23.21 | 580 | 21.81 | 580 | 19.94 | 580 | 17.79 |
| 590 | 23.21 | 590 | 21.81 | 590 | 19.96 | 590 | 17.80 |
| 600 | 23.21 | 600 | 21.81 | 600 | 19.97 | 600 | 17.82 |

Figure : Time-temperature diagrams of KCl in dewar vessel.

Figure : Time-temperature diagrams of KCl in cup.

Table : Measured dataset of CaCl2.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 23.47 | 0 | 23.39 | 0 | 24.50 | 0 | 22.02 |
| 10 | 23.48 | 10 | 23.42 | 10 | 24.50 | 10 | 22.02 |
| 20 | 23.48 | 20 | 23.44 | 20 | 24.50 | 20 | 22.02 |
| 30 | 23.47 | 30 | 23.45 | 30 | 24.50 | 30 | 22.03 |
| 40 | 23.48 | 40 | 23.47 | 40 | 24.51 | 40 | 22.03 |
| 50 | 23.48 | 50 | 23.49 | 50 | 24.52 | 50 | 22.04 |
| 60 | 23.49 | 60 | 23.50 | 60 | 24.52 | 60 | 22.04 |
| 70 | 23.50 | 70 | 23.52 | 70 | 24.53 | 70 | 22.04 |
| 80 | 23.51 | 80 | 23.54 | 80 | 24.53 | 80 | 22.05 |
| 90 | 23.52 | 90 | 23.55 | 90 | 24.53 | 90 | 22.05 |
| 100 | 23.53 | 100 | 23.56 | 100 | 24.54 | 100 | 22.06 |
| 110 | 23.54 | 110 | 23.57 | 110 | 24.54 | 110 | 22.06 |
| 120 | 23.55 | 120 | 23.59 | 120 | 24.55 | 120 | 22.07 |
| 130 | 23.57 | 130 | 23.60 | 130 | 24.55 | 130 | 22.07 |
| 140 | 23.58 | 140 | 23.61 | 140 | 24.55 | 140 | 22.07 |
| 150 | 23.59 | 150 | 23.61 | 150 | 24.55 | 150 | 22.08 |
| 160 | 23.60 | 160 | 23.62 | 160 | 24.56 | 160 | 22.08 |
| 170 | 23.61 | 170 | 23.63 | 170 | 24.56 | 170 | 22.08 |
| 180 | 23.62 | 180 | 23.64 | 180 | 24.57 | 180 | 22.09 |
| 190 | 23.62 | 190 | 23.65 | 190 | 24.57 | 190 | 22.09 |
| 200 | 23.63 | 200 | 23.65 | 200 | 24.57 | 200 | 22.10 |
| 210 | 23.64 | 210 | 23.66 | 210 | 24.57 | 210 | 22.10 |
| 220 | 23.65 | 220 | 23.67 | 220 | 24.58 | 220 | 22.10 |
| 230 | 23.66 | 230 | 23.67 | 230 | 24.58 | 230 | 22.11 |
| 240 | 23.66 | 240 | 23.68 | 240 | 24.58 | 240 | 22.11 |
| 250 | 23.67 | 250 | 23.68 | 250 | 24.59 | 250 | 22.11 |
| 260 | 23.68 | 260 | 23.69 | 260 | 24.59 | 260 | 22.12 |
| 270 | 23.68 | 270 | 23.70 | 270 | 24.59 | 270 | 22.12 |
| 280 | 23.69 | 280 | 23.71 | 280 | 24.60 | 280 | 22.12 |
| 290 | 23.69 | 290 | 23.71 | 290 | 24.60 | 290 | 22.13 |
| 300 | 23.67 | 300 | 23.71 | 300 | 24.60 | 300 | 22.13 |
| 310 | 24.14 | 310 | 24.07 | 310 | 25.44 | 310 | 25.19 |
| 320 | 24.87 | 320 | 24.54 | 320 | 27.31 | 320 | 26.26 |
| 330 | 25.65 | 330 | 25.16 | 330 | 28.33 | 330 | 27.43 |
| 340 | 26.39 | 340 | 25.76 | 340 | 29.24 | 340 | 28.62 |
| 350 | 27.01 | 350 | 26.27 | 350 | 29.85 | 350 | 29.14 |
| 360 | 27.59 | 360 | 26.73 | 360 | 30.14 | 360 | 30.01 |
| 370 | 27.94 | 370 | 27.09 | 370 | 30.40 | 370 | 30.88 |
| 380 | 28.25 | 380 | 27.45 | 380 | 30.56 | 380 | 31.43 |
| 390 | 28.49 | 390 | 27.72 | 390 | 30.70 | 390 | 31.76 |
| 400 | 28.72 | 400 | 27.95 | 400 | 30.85 | 400 | 31.82 |
| 410 | 28.90 | 410 | 28.15 | 410 | 30.94 | 410 | 31.90 |
| 420 | 29.07 | 420 | 28.33 | 420 | 31.02 | 420 | 31.95 |
| 430 | 29.26 | 430 | 28.48 | 430 | 31.09 | 430 | 32.00 |
| 440 | 29.37 | 440 | 28.64 | 440 | 31.14 | 440 | 32.05 |
| 450 | 29.44 | 450 | 28.81 | 450 | 31.19 | 450 | 32.09 |
| 460 | 29.53 | 460 | 28.96 | 460 | 31.29 | 460 | 32.12 |
| 470 | 29.62 | 470 | 29.06 | 470 | 31.38 | 470 | 32.19 |
| 480 | 29.72 | 480 | 29.14 | 480 | 31.41 | 480 | 32.20 |
| 490 | 29.78 | 490 | 29.25 | 490 | 31.45 | 490 | 32.24 |
| 500 | 29.85 | 500 | 29.34 | 500 | 31.47 | 500 | 32.27 |
| 510 | 29.91 | 510 | 29.41 | 510 | 31.47 | 510 | 32.30 |
| 520 | 29.96 | 520 | 29.48 | 520 | 31.46 | 520 | 32.28 |
| 530 | 30.00 | 530 | 29.54 | 530 | 31.45 | 530 | 32.27 |
| 540 | 30.03 | 540 | 29.63 | 540 | 31.45 | 540 | 32.25 |
| 550 | 30.05 | 550 | 29.70 | 550 | 31.44 | 550 | 32.23 |
| 560 | 30.06 | 560 | 29.75 | 560 | 31.44 | 560 | 32.20 |
| 570 | 30.07 | 570 | 29.78 | 570 | 31.43 | 570 | 32.18 |
| 580 | 30.06 | 580 | 29.82 | 580 | 31.42 | 580 | 32.14 |
| 590 | 30.05 | 590 | 29.84 | 590 | 31.41 | 590 | 32.09 |
| 600 | 30.05 | 600 | 29.85 | 600 | 31.41 | 600 | 32.06 |

Figure : Time-temperature diagrams of CaCL2 in dewar vessel.

Figure : Time-temperature diagrams of CaCl2 in cup.

Table : Measured dataset of Na2CO3.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 23.76 | 0 | 23.21 | 0 | 24.60 | 0 | 22.70 |
| 10 | 23.78 | 10 | 23.31 | 10 | 24.61 | 10 | 22.70 |
| 20 | 23.82 | 20 | 23.35 | 20 | 24.62 | 20 | 22.71 |
| 30 | 23.84 | 30 | 23.39 | 30 | 24.62 | 30 | 22.71 |
| 40 | 23.86 | 40 | 23.42 | 40 | 24.62 | 40 | 22.71 |
| 50 | 23.88 | 50 | 23.45 | 50 | 24.63 | 50 | 22.71 |
| 60 | 23.89 | 60 | 23.48 | 60 | 24.63 | 60 | 22.72 |
| 70 | 23.91 | 70 | 23.51 | 70 | 24.64 | 70 | 22.72 |
| 80 | 23.92 | 80 | 23.54 | 80 | 24.64 | 80 | 22.72 |
| 90 | 23.93 | 90 | 23.56 | 90 | 24.65 | 90 | 22.72 |
| 100 | 23.93 | 100 | 23.59 | 100 | 24.65 | 100 | 22.72 |
| 110 | 23.94 | 110 | 23.61 | 110 | 24.66 | 110 | 22.73 |
| 120 | 23.95 | 120 | 23.63 | 120 | 24.66 | 120 | 22.73 |
| 130 | 23.96 | 130 | 23.64 | 130 | 24.67 | 130 | 22.73 |
| 140 | 23.97 | 140 | 23.66 | 140 | 24.67 | 140 | 22.74 |
| 150 | 23.98 | 150 | 23.67 | 150 | 24.68 | 150 | 22.74 |
| 160 | 23.99 | 160 | 23.70 | 160 | 24.68 | 160 | 22.74 |
| 170 | 24.00 | 170 | 23.71 | 170 | 24.69 | 170 | 22.74 |
| 180 | 24.01 | 180 | 23.72 | 180 | 24.69 | 180 | 22.74 |
| 190 | 24.02 | 190 | 23.73 | 190 | 24.70 | 190 | 22.74 |
| 200 | 24.03 | 200 | 23.74 | 200 | 24.70 | 200 | 22.75 |
| 210 | 24.03 | 210 | 23.75 | 210 | 24.71 | 210 | 22.75 |
| 220 | 24.04 | 220 | 23.76 | 220 | 24.71 | 220 | 22.75 |
| 230 | 24.05 | 230 | 23.78 | 230 | 24.72 | 230 | 22.76 |
| 240 | 24.05 | 240 | 23.79 | 240 | 24.72 | 240 | 22.76 |
| 250 | 24.06 | 250 | 23.80 | 250 | 24.72 | 250 | 22.76 |
| 260 | 24.06 | 260 | 23.81 | 260 | 24.73 | 260 | 22.76 |
| 270 | 24.07 | 270 | 23.82 | 270 | 24.73 | 270 | 22.76 |
| 280 | 24.07 | 280 | 23.83 | 280 | 24.74 | 280 | 22.77 |
| 290 | 24.08 | 290 | 23.84 | 290 | 24.74 | 290 | 22.77 |
| 300 | 24.08 | 300 | 23.85 | 300 | 24.74 | 300 | 22.77 |
| 310 | 24.59 | 310 | 24.05 | 310 | 25.74 | 310 | 24.81 |
| 320 | 24.97 | 320 | 24.46 | 320 | 27.29 | 320 | 25.37 |
| 330 | 25.38 | 330 | 24.86 | 330 | 27.72 | 330 | 25.65 |
| 340 | 25.69 | 340 | 25.20 | 340 | 28.07 | 340 | 25.88 |
| 350 | 25.95 | 350 | 25.47 | 350 | 28.28 | 350 | 26.03 |
| 360 | 26.16 | 360 | 25.71 | 360 | 28.40 | 360 | 26.16 |
| 370 | 26.30 | 370 | 25.88 | 370 | 28.51 | 370 | 26.26 |
| 380 | 26.42 | 380 | 26.02 | 380 | 28.58 | 380 | 26.33 |
| 390 | 26.51 | 390 | 26.14 | 390 | 28.61 | 390 | 26.41 |
| 400 | 26.60 | 400 | 26.25 | 400 | 28.70 | 400 | 26.46 |
| 410 | 26.69 | 410 | 26.33 | 410 | 28.72 | 410 | 26.50 |
| 420 | 26.75 | 420 | 26.41 | 420 | 28.76 | 420 | 26.54 |
| 430 | 26.81 | 430 | 26.48 | 430 | 28.77 | 430 | 26.57 |
| 440 | 26.85 | 440 | 26.54 | 440 | 28.78 | 440 | 26.59 |
| 450 | 26.90 | 450 | 26.59 | 450 | 28.79 | 450 | 26.61 |
| 460 | 26.95 | 460 | 26.64 | 460 | 28.79 | 460 | 26.63 |
| 470 | 26.99 | 470 | 26.68 | 470 | 28.79 | 470 | 26.64 |
| 480 | 27.02 | 480 | 26.70 | 480 | 28.79 | 480 | 26.66 |
| 490 | 27.02 | 490 | 26.72 | 490 | 28.79 | 490 | 26.86 |
| 500 | 27.05 | 500 | 26.75 | 500 | 28.79 | 500 | 26.90 |
| 510 | 27.10 | 510 | 26.78 | 510 | 28.79 | 510 | 26.93 |
| 520 | 27.13 | 520 | 26.80 | 520 | 28.78 | 520 | 26.95 |
| 530 | 27.14 | 530 | 26.82 | 530 | 28.78 | 530 | 26.95 |
| 540 | 27.15 | 540 | 26.82 | 540 | 28.77 | 540 | 26.95 |
| 550 | 27.20 | 550 | 26.83 | 550 | 28.76 | 550 | 26.95 |
| 560 | 27.21 | 560 | 26.84 | 560 | 28.76 | 560 | 26.95 |
| 570 | 27.22 | 570 | 26.85 | 570 | 28.75 | 570 | 26.95 |
| 580 | 27.25 | 580 | 26.85 | 580 | 28.74 | 580 | 26.95 |
| 590 | 27.26 | 590 | 26.85 | 590 | 28.73 | 590 | 26.95 |
| 600 | 27.26 | 600 | 26.85 | 600 | 28.73 | 600 | 26.95 |

Figure : Time-temperature diagrams of Na2CO3 in dewar vessel.

Figure : Time-temperature diagrams of Na2CO3 in cup.

Table : Measured dataset of K2CO3.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 23.62 | 0 | 23.54 | 0 | 24.37 | 0 | 22.44 |
| 10 | 23.68 | 10 | 23.60 | 10 | 24.43 | 10 | 22.45 |
| 20 | 23.68 | 20 | 23.65 | 20 | 24.46 | 20 | 22.46 |
| 30 | 23.68 | 30 | 23.69 | 30 | 24.48 | 30 | 22.47 |
| 40 | 23.69 | 40 | 23.73 | 40 | 24.50 | 40 | 22.48 |
| 50 | 23.70 | 50 | 23.76 | 50 | 24.52 | 50 | 22.49 |
| 60 | 23.71 | 60 | 23.78 | 60 | 24.54 | 60 | 22.49 |
| 70 | 23.72 | 70 | 23.81 | 70 | 24.56 | 70 | 22.49 |
| 80 | 23.74 | 80 | 23.83 | 80 | 24.57 | 80 | 22.50 |
| 90 | 23.75 | 90 | 23.85 | 90 | 24.59 | 90 | 22.51 |
| 100 | 23.76 | 100 | 23.86 | 100 | 24.60 | 100 | 22.51 |
| 110 | 23.77 | 110 | 23.88 | 110 | 24.61 | 110 | 22.51 |
| 120 | 23.78 | 120 | 23.89 | 120 | 24.62 | 120 | 22.52 |
| 130 | 23.79 | 130 | 23.90 | 130 | 24.63 | 130 | 22.53 |
| 140 | 23.80 | 140 | 23.92 | 140 | 24.65 | 140 | 22.53 |
| 150 | 23.81 | 150 | 23.93 | 150 | 24.66 | 150 | 22.53 |
| 160 | 23.82 | 160 | 23.94 | 160 | 24.67 | 160 | 22.54 |
| 170 | 23.83 | 170 | 23.95 | 170 | 24.68 | 170 | 22.54 |
| 180 | 23.84 | 180 | 23.96 | 180 | 24.68 | 180 | 22.55 |
| 190 | 23.85 | 190 | 23.97 | 190 | 24.69 | 190 | 22.55 |
| 200 | 23.86 | 200 | 23.97 | 200 | 24.70 | 200 | 22.55 |
| 210 | 23.87 | 210 | 23.98 | 210 | 24.71 | 210 | 22.56 |
| 220 | 23.88 | 220 | 23.99 | 220 | 24.71 | 220 | 22.56 |
| 230 | 23.89 | 230 | 24.00 | 230 | 24.71 | 230 | 22.57 |
| 240 | 23.90 | 240 | 24.01 | 240 | 24.72 | 240 | 22.57 |
| 250 | 23.91 | 250 | 24.01 | 250 | 24.73 | 250 | 22.57 |
| 260 | 23.92 | 260 | 24.02 | 260 | 24.73 | 260 | 22.58 |
| 270 | 23.92 | 270 | 24.02 | 270 | 24.74 | 270 | 22.58 |
| 280 | 23.93 | 280 | 24.03 | 280 | 24.75 | 280 | 22.58 |
| 290 | 23.93 | 290 | 24.04 | 290 | 24.75 | 290 | 22.59 |
| 300 | 23.95 | 300 | 24.04 | 300 | 24.76 | 300 | 22.60 |
| 310 | 24.61 | 310 | 24.54 | 310 | 24.77 | 310 | 24.85 |
| 320 | 25.04 | 320 | 24.92 | 320 | 24.78 | 320 | 25.39 |
| 330 | 25.40 | 330 | 25.25 | 330 | 24.79 | 330 | 25.57 |
| 340 | 25.68 | 340 | 25.51 | 340 | 24.80 | 340 | 25.67 |
| 350 | 25.88 | 350 | 25.72 | 350 | 24.80 | 350 | 25.68 |
| 360 | 26.04 | 360 | 25.87 | 360 | 24.84 | 360 | 25.63 |
| 370 | 26.17 | 370 | 25.98 | 370 | 24.87 | 370 | 25.62 |
| 380 | 26.28 | 380 | 26.07 | 380 | 24.88 | 380 | 25.63 |
| 390 | 26.38 | 390 | 26.15 | 390 | 24.90 | 390 | 25.65 |
| 400 | 26.48 | 400 | 26.21 | 400 | 24.92 | 400 | 25.70 |
| 410 | 26.56 | 410 | 26.26 | 410 | 24.94 | 410 | 25.74 |
| 420 | 26.62 | 420 | 26.29 | 420 | 24.96 | 420 | 25.78 |
| 430 | 26.69 | 430 | 26.32 | 430 | 24.98 | 430 | 25.81 |
| 440 | 26.74 | 440 | 26.34 | 440 | 24.99 | 440 | 25.83 |
| 450 | 26.80 | 450 | 26.36 | 450 | 25.00 | 450 | 25.83 |
| 460 | 26.84 | 460 | 26.39 | 460 | 25.01 | 460 | 25.83 |
| 470 | 26.87 | 470 | 26.41 | 470 | 25.03 | 470 | 25.83 |
| 480 | 26.89 | 480 | 26.43 | 480 | 25.04 | 480 | 25.82 |
| 490 | 26.92 | 490 | 26.45 | 490 | 25.05 | 490 | 25.82 |
| 500 | 26.92 | 500 | 26.46 | 500 | 25.06 | 500 | 25.82 |
| 510 | 26.92 | 510 | 26.47 | 510 | 25.07 | 510 | 25.82 |
| 520 | 26.93 | 520 | 26.47 | 520 | 25.08 | 520 | 25.82 |
| 530 | 26.93 | 530 | 26.49 | 530 | 25.09 | 530 | 25.82 |
| 540 | 26.94 | 540 | 26.49 | 540 | 25.10 | 540 | 25.82 |
| 550 | 26.93 | 550 | 26.49 | 550 | 25.11 | 550 | 25.82 |
| 560 | 26.92 | 560 | 26.50 | 560 | 25.12 | 560 | 25.81 |
| 570 | 26.92 | 570 | 26.50 | 570 | 25.12 | 570 | 25.80 |
| 580 | 26.89 | 580 | 26.51 | 580 | 25.13 | 580 | 25.80 |
| 590 | 26.88 | 590 | 26.52 | 590 | 25.14 | 590 | 25.80 |
| 600 | 26.89 | 600 | 26.52 | 600 | 25.14 | 600 | 25.80 |

Figure : Time-temperature diagrams of K2CO3 in dewar vessel.

Figure : Time-temperature diagrams of K­2CO3 in cup.

Table : Measured dataset of K2SO4

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 23.84 | 0 | 23.65 | 0 | 24.65 | 0 | 23.48 |
| 10 | 23.86 | 10 | 23.66 | 10 | 24.68 | 10 | 24.07 |
| 20 | 23.85 | 20 | 23.65 | 20 | 24.71 | 20 | 24.16 |
| 30 | 23.86 | 30 | 23.63 | 30 | 24.73 | 30 | 24.23 |
| 40 | 23.86 | 40 | 23.62 | 40 | 24.74 | 40 | 24.28 |
| 50 | 23.87 | 50 | 23.62 | 50 | 24.75 | 50 | 24.31 |
| 60 | 23.87 | 60 | 23.62 | 60 | 24.76 | 60 | 24.32 |
| 70 | 23.88 | 70 | 23.62 | 70 | 24.77 | 70 | 24.34 |
| 80 | 23.89 | 80 | 23.63 | 80 | 24.78 | 80 | 24.35 |
| 90 | 23.89 | 90 | 23.64 | 90 | 24.79 | 90 | 24.36 |
| 100 | 23.90 | 100 | 23.65 | 100 | 24.80 | 100 | 24.37 |
| 110 | 23.91 | 110 | 23.66 | 110 | 24.80 | 110 | 24.38 |
| 120 | 23.92 | 120 | 23.67 | 120 | 24.81 | 120 | 24.38 |
| 130 | 23.92 | 130 | 23.69 | 130 | 24.82 | 130 | 24.39 |
| 140 | 23.93 | 140 | 23.70 | 140 | 24.82 | 140 | 24.39 |
| 150 | 23.94 | 150 | 23.72 | 150 | 24.83 | 150 | 24.39 |
| 160 | 23.95 | 160 | 23.73 | 160 | 24.84 | 160 | 24.39 |
| 170 | 23.95 | 170 | 23.75 | 170 | 24.84 | 170 | 24.39 |
| 180 | 23.96 | 180 | 23.76 | 180 | 24.85 | 180 | 24.40 |
| 190 | 23.97 | 190 | 23.78 | 190 | 24.86 | 190 | 24.40 |
| 200 | 23.97 | 200 | 23.79 | 200 | 24.86 | 200 | 24.40 |
| 210 | 23.98 | 210 | 23.81 | 210 | 24.87 | 210 | 24.40 |
| 220 | 23.99 | 220 | 23.82 | 220 | 24.87 | 220 | 24.40 |
| 230 | 24.00 | 230 | 23.84 | 230 | 24.88 | 230 | 24.40 |
| 240 | 24.00 | 240 | 23.85 | 240 | 24.88 | 240 | 24.40 |
| 250 | 24.01 | 250 | 23.86 | 250 | 24.89 | 250 | 24.40 |
| 260 | 24.01 | 260 | 23.87 | 260 | 24.90 | 260 | 24.40 |
| 270 | 24.02 | 270 | 23.88 | 270 | 24.90 | 270 | 24.40 |
| 280 | 24.02 | 280 | 23.90 | 280 | 24.91 | 280 | 24.40 |
| 290 | 24.03 | 290 | 23.91 | 290 | 24.91 | 290 | 24.40 |
| 300 | 24.04 | 300 | 23.92 | 300 | 24.91 | 300 | 24.38 |
| 310 | 23.93 | 310 | 23.92 | 310 | 24.53 | 310 | 23.68 |
| 320 | 23.86 | 320 | 23.88 | 320 | 24.05 | 320 | 23.50 |
| 330 | 23.76 | 330 | 23.82 | 330 | 23.67 | 330 | 23.37 |
| 340 | 23.65 | 340 | 23.75 | 340 | 23.42 | 340 | 23.23 |
| 350 | 23.56 | 350 | 23.68 | 350 | 23.26 | 350 | 23.19 |
| 360 | 23.48 | 360 | 23.62 | 360 | 23.13 | 360 | 23.16 |
| 370 | 23.40 | 370 | 23.57 | 370 | 23.04 | 370 | 23.14 |
| 380 | 23.34 | 380 | 23.52 | 380 | 22.97 | 380 | 23.11 |
| 390 | 23.29 | 390 | 23.47 | 390 | 22.92 | 390 | 23.09 |
| 400 | 23.24 | 400 | 23.43 | 400 | 22.89 | 400 | 23.07 |
| 410 | 23.20 | 410 | 23.40 | 410 | 22.87 | 410 | 23.05 |
| 420 | 23.17 | 420 | 23.37 | 420 | 22.85 | 420 | 23.05 |
| 430 | 23.14 | 430 | 23.34 | 430 | 22.84 | 430 | 23.05 |
| 440 | 23.12 | 440 | 23.32 | 440 | 22.84 | 440 | 23.04 |
| 450 | 23.10 | 450 | 23.30 | 450 | 22.84 | 450 | 23.04 |
| 460 | 23.09 | 460 | 23.29 | 460 | 22.83 | 460 | 23.05 |
| 470 | 23.07 | 470 | 23.27 | 470 | 22.83 | 470 | 23.05 |
| 480 | 23.06 | 480 | 23.26 | 480 | 22.83 | 480 | 23.06 |
| 490 | 23.05 | 490 | 23.24 | 490 | 22.84 | 490 | 23.06 |
| 500 | 23.05 | 500 | 23.23 | 500 | 22.84 | 500 | 23.07 |
| 510 | 23.04 | 510 | 23.23 | 510 | 22.85 | 510 | 23.07 |
| 520 | 23.03 | 520 | 23.22 | 520 | 22.85 | 520 | 23.08 |
| 530 | 23.03 | 530 | 23.21 | 530 | 22.86 | 530 | 23.08 |
| 540 | 23.03 | 540 | 23.20 | 540 | 22.86 | 540 | 23.09 |
| 550 | 23.03 | 550 | 23.20 | 550 | 22.87 | 550 | 23.09 |
| 560 | 23.02 | 560 | 23.19 | 560 | 22.89 | 560 | 23.09 |
| 570 | 23.02 | 570 | 23.19 | 570 | 22.91 | 570 | 23.09 |
| 580 | 23.02 | 580 | 23.19 | 580 | 22.92 | 580 | 23.09 |
| 590 | 23.02 | 590 | 23.18 | 590 | 22.92 | 590 | 23.09 |
| 600 | 23.02 | 600 | 23.19 | 600 | 22.92 | 600 | 23.09 |

Figure : Time-temperature diagrams of K2SO4 in dewar vessel.

Figure : Time-temperature diagrams of K2SO4 in cup.

Table : Measured dataset of KNO3

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 23.53 | 0 | 22.89 | 0 | 25.53 | 0 | 23.16 |
| 10 | 23.59 | 10 | 23.03 | 10 | 25.54 | 10 | 23.18 |
| 20 | 23.60 | 20 | 23.10 | 20 | 25.54 | 20 | 23.20 |
| 30 | 23.62 | 30 | 23.15 | 30 | 25.55 | 30 | 23.21 |
| 40 | 23.65 | 40 | 23.25 | 40 | 25.55 | 40 | 23.22 |
| 50 | 23.68 | 50 | 23.31 | 50 | 25.56 | 50 | 23.22 |
| 60 | 23.72 | 60 | 23.37 | 60 | 25.56 | 60 | 23.23 |
| 70 | 23.75 | 70 | 23.42 | 70 | 25.57 | 70 | 23.24 |
| 80 | 23.78 | 80 | 23.46 | 80 | 25.57 | 80 | 23.24 |
| 90 | 23.81 | 90 | 23.50 | 90 | 25.58 | 90 | 23.25 |
| 100 | 23.84 | 100 | 23.55 | 100 | 25.58 | 100 | 23.25 |
| 110 | 23.86 | 110 | 23.58 | 110 | 25.59 | 110 | 23.26 |
| 120 | 23.89 | 120 | 23.61 | 120 | 25.59 | 120 | 23.26 |
| 130 | 23.91 | 130 | 23.64 | 130 | 25.59 | 130 | 23.27 |
| 140 | 23.93 | 140 | 23.66 | 140 | 25.60 | 140 | 23.27 |
| 150 | 23.96 | 150 | 23.69 | 150 | 25.60 | 150 | 23.27 |
| 160 | 23.98 | 160 | 23.71 | 160 | 25.61 | 160 | 23.28 |
| 170 | 24.00 | 170 | 23.74 | 170 | 25.61 | 170 | 23.28 |
| 180 | 24.02 | 180 | 23.76 | 180 | 25.62 | 180 | 23.29 |
| 190 | 24.03 | 190 | 23.79 | 190 | 25.62 | 190 | 23.29 |
| 200 | 24.05 | 200 | 23.81 | 200 | 25.62 | 200 | 23.29 |
| 210 | 24.07 | 210 | 23.83 | 210 | 25.63 | 210 | 23.30 |
| 220 | 24.08 | 220 | 23.85 | 220 | 25.63 | 220 | 23.30 |
| 230 | 24.10 | 230 | 23.86 | 230 | 25.64 | 230 | 23.31 |
| 240 | 24.11 | 240 | 23.88 | 240 | 25.64 | 240 | 23.31 |
| 250 | 24.12 | 250 | 23.90 | 250 | 25.65 | 250 | 23.32 |
| 260 | 24.13 | 260 | 23.91 | 260 | 25.65 | 260 | 23.32 |
| 270 | 24.15 | 270 | 23.93 | 270 | 25.65 | 270 | 23.32 |
| 280 | 24.15 | 280 | 23.94 | 280 | 25.65 | 280 | 23.33 |
| 290 | 24.16 | 290 | 23.96 | 290 | 25.66 | 290 | 23.33 |
| 300 | 24.17 | 300 | 23.98 | 300 | 25.66 | 300 | 23.33 |
| 310 | 23.90 | 310 | 23.83 | 310 | 24.75 | 310 | 21.54 |
| 320 | 23.58 | 320 | 23.49 | 320 | 23.97 | 320 | 20.03 |
| 330 | 23.26 | 330 | 23.18 | 330 | 23.58 | 330 | 19.02 |
| 340 | 22.99 | 340 | 22.90 | 340 | 23.01 | 340 | 18.62 |
| 350 | 22.77 | 350 | 22.63 | 350 | 22.59 | 350 | 18.44 |
| 360 | 22.60 | 360 | 22.42 | 360 | 22.02 | 360 | 18.31 |
| 370 | 22.46 | 370 | 22.24 | 370 | 21.65 | 370 | 18.23 |
| 380 | 22.35 | 380 | 22.10 | 380 | 21.34 | 380 | 18.15 |
| 390 | 22.24 | 390 | 21.99 | 390 | 21.14 | 390 | 18.11 |
| 400 | 22.16 | 400 | 21.91 | 400 | 20.78 | 400 | 18.10 |
| 410 | 22.09 | 410 | 21.82 | 410 | 20.73 | 410 | 18.09 |
| 420 | 22.03 | 420 | 21.75 | 420 | 20.66 | 420 | 18.05 |
| 430 | 21.98 | 430 | 21.69 | 430 | 20.62 | 430 | 18.03 |
| 440 | 21.94 | 440 | 21.64 | 440 | 20.60 | 440 | 18.04 |
| 450 | 21.90 | 450 | 21.59 | 450 | 20.59 | 450 | 18.06 |
| 460 | 21.86 | 460 | 21.56 | 460 | 20.58 | 460 | 18.06 |
| 470 | 21.82 | 470 | 21.53 | 470 | 20.57 | 470 | 18.07 |
| 480 | 21.80 | 480 | 21.51 | 480 | 20.57 | 480 | 18.07 |
| 490 | 21.77 | 490 | 21.49 | 490 | 20.57 | 490 | 18.08 |
| 500 | 21.75 | 500 | 21.48 | 500 | 20.58 | 500 | 18.10 |
| 510 | 21.72 | 510 | 21.47 | 510 | 20.59 | 510 | 18.11 |
| 520 | 21.71 | 520 | 21.47 | 520 | 20.60 | 520 | 18.11 |
| 530 | 21.69 | 530 | 21.45 | 530 | 20.61 | 530 | 18.15 |
| 540 | 21.68 | 540 | 21.44 | 540 | 20.62 | 540 | 18.17 |
| 550 | 21.67 | 550 | 21.43 | 550 | 20.63 | 550 | 18.18 |
| 560 | 21.65 | 560 | 21.43 | 560 | 20.65 | 560 | 18.19 |
| 570 | 21.64 | 570 | 21.42 | 570 | 20.66 | 570 | 18.20 |
| 580 | 21.63 | 580 | 21.41 | 580 | 20.67 | 580 | 18.24 |
| 590 | 21.62 | 590 | 21.41 | 590 | 20.69 | 590 | 18.25 |
| 600 | 21.62 | 600 | 21.42 | 600 | 20.70 | 600 | 18.28 |

Figure : Time-temperature diagrams of KNO3 in dewar vessel.

Figure : Time-temperature diagrams of KNO3 in cup.

Table : Measured dataset of NaAc.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 22.60 | 0 | 21.92 | 0 | 25.03 | 0 | 22.38 |
| 10 | 22.60 | 10 | 21.98 | 10 | 25.06 | 10 | 22.60 |
| 20 | 22.61 | 20 | 22.00 | 20 | 25.07 | 20 | 22.74 |
| 30 | 22.62 | 30 | 22.02 | 30 | 25.08 | 30 | 22.80 |
| 40 | 22.65 | 40 | 22.03 | 40 | 25.09 | 40 | 22.86 |
| 50 | 22.67 | 50 | 22.06 | 50 | 25.10 | 50 | 22.91 |
| 60 | 22.70 | 60 | 22.08 | 60 | 25.11 | 60 | 22.94 |
| 70 | 22.71 | 70 | 22.11 | 70 | 25.11 | 70 | 22.97 |
| 80 | 22.73 | 80 | 22.13 | 80 | 25.12 | 80 | 22.98 |
| 90 | 22.75 | 90 | 22.15 | 90 | 25.12 | 90 | 23.01 |
| 100 | 22.76 | 100 | 22.17 | 100 | 25.13 | 100 | 23.03 |
| 110 | 22.77 | 110 | 22.19 | 110 | 25.13 | 110 | 23.04 |
| 120 | 22.79 | 120 | 22.21 | 120 | 25.14 | 120 | 23.05 |
| 130 | 22.80 | 130 | 22.22 | 130 | 25.14 | 130 | 23.06 |
| 140 | 22.80 | 140 | 22.24 | 140 | 25.15 | 140 | 23.08 |
| 150 | 22.81 | 150 | 22.25 | 150 | 25.15 | 150 | 23.09 |
| 160 | 22.82 | 160 | 22.27 | 160 | 25.16 | 160 | 23.10 |
| 170 | 22.83 | 170 | 22.28 | 170 | 25.16 | 170 | 23.11 |
| 180 | 22.83 | 180 | 22.29 | 180 | 25.17 | 180 | 23.12 |
| 190 | 22.83 | 190 | 22.31 | 190 | 25.17 | 190 | 23.13 |
| 200 | 22.84 | 200 | 22.32 | 200 | 25.18 | 200 | 23.14 |
| 210 | 22.84 | 210 | 22.33 | 210 | 25.18 | 210 | 23.14 |
| 220 | 22.85 | 220 | 22.35 | 220 | 25.18 | 220 | 23.14 |
| 230 | 22.85 | 230 | 22.36 | 230 | 25.19 | 230 | 23.15 |
| 240 | 22.85 | 240 | 22.37 | 240 | 25.19 | 240 | 23.16 |
| 250 | 22.85 | 250 | 22.38 | 250 | 25.20 | 250 | 23.17 |
| 260 | 22.86 | 260 | 22.39 | 260 | 25.20 | 260 | 23.17 |
| 270 | 22.86 | 270 | 22.40 | 270 | 25.20 | 270 | 23.18 |
| 280 | 22.86 | 280 | 22.41 | 280 | 25.21 | 280 | 23.18 |
| 290 | 22.86 | 290 | 22.42 | 290 | 25.21 | 290 | 23.19 |
| 300 | 22.86 | 300 | 22.43 | 300 | 25.22 | 300 | 23.20 |
| 310 | 23.11 | 310 | 22.60 | 310 | 25.78 | 310 | 23.89 |
| 320 | 23.35 | 320 | 22.85 | 320 | 26.59 | 320 | 24.86 |
| 330 | 23.57 | 330 | 23.09 | 330 | 26.97 | 330 | 25.33 |
| 340 | 23.78 | 340 | 23.32 | 340 | 27.18 | 340 | 25.67 |
| 350 | 23.98 | 350 | 23.54 | 350 | 27.31 | 350 | 25.84 |
| 360 | 24.17 | 360 | 23.68 | 360 | 27.39 | 360 | 25.94 |
| 370 | 24.37 | 370 | 23.79 | 370 | 27.46 | 370 | 26.00 |
| 380 | 24.53 | 380 | 23.90 | 380 | 27.50 | 380 | 26.05 |
| 390 | 24.67 | 390 | 24.01 | 390 | 27.53 | 390 | 26.08 |
| 400 | 24.79 | 400 | 24.09 | 400 | 27.57 | 400 | 26.11 |
| 410 | 24.88 | 410 | 24.16 | 410 | 27.59 | 410 | 26.14 |
| 420 | 24.94 | 420 | 24.22 | 420 | 27.62 | 420 | 26.16 |
| 430 | 24.99 | 430 | 24.27 | 430 | 27.64 | 430 | 26.17 |
| 440 | 25.05 | 440 | 24.33 | 440 | 27.65 | 440 | 26.18 |
| 450 | 25.08 | 450 | 24.38 | 450 | 27.66 | 450 | 26.19 |
| 460 | 25.13 | 460 | 24.41 | 460 | 27.68 | 460 | 26.20 |
| 470 | 25.16 | 470 | 24.45 | 470 | 27.69 | 470 | 26.21 |
| 480 | 25.18 | 480 | 24.48 | 480 | 27.69 | 480 | 26.21 |
| 490 | 25.21 | 490 | 24.53 | 490 | 27.70 | 490 | 26.22 |
| 500 | 25.25 | 500 | 24.56 | 500 | 27.71 | 500 | 26.22 |
| 510 | 25.29 | 510 | 24.59 | 510 | 27.71 | 510 | 26.22 |
| 520 | 25.32 | 520 | 24.59 | 520 | 27.71 | 520 | 26.22 |
| 530 | 25.33 | 530 | 24.61 | 530 | 27.72 | 530 | 26.22 |
| 540 | 25.35 | 540 | 24.62 | 540 | 27.73 | 540 | 26.22 |
| 550 | 25.37 | 550 | 24.65 | 550 | 27.74 | 550 | 26.21 |
| 560 | 25.39 | 560 | 24.68 | 560 | 27.74 | 560 | 26.21 |
| 570 | 25.41 | 570 | 24.69 | 570 | 27.74 | 570 | 26.21 |
| 580 | 25.41 | 580 | 24.71 | 580 | 27.74 | 580 | 26.21 |
| 590 | 25.41 | 590 | 24.73 | 590 | 27.74 | 590 | 26.20 |
| 600 | 25.42 | 600 | 24.74 | 600 | 27.75 | 600 | 26.20 |

Figure : Time-temperature diagrams of NaAC in dewar vessel

Figure : Time-temperature diagrams of NaAC in cup.

Table : Measured dataset of NaAC·3H2O

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 23.02 | 0 | 22.52 | 0 | 23.08 | 0 | 22.25 |
| 10 | 23.03 | 10 | 22.54 | 10 | 23.08 | 10 | 22.31 |
| 20 | 23.03 | 20 | 22.56 | 20 | 23.08 | 20 | 22.37 |
| 30 | 23.04 | 30 | 22.58 | 30 | 23.08 | 30 | 22.42 |
| 40 | 23.05 | 40 | 22.59 | 40 | 23.08 | 40 | 22.46 |
| 50 | 23.06 | 50 | 22.61 | 50 | 23.09 | 50 | 22.49 |
| 60 | 23.07 | 60 | 22.62 | 60 | 23.09 | 60 | 22.52 |
| 70 | 23.08 | 70 | 22.63 | 70 | 23.09 | 70 | 22.54 |
| 80 | 23.09 | 80 | 22.64 | 80 | 23.10 | 80 | 22.56 |
| 90 | 23.10 | 90 | 22.65 | 90 | 23.10 | 90 | 22.58 |
| 100 | 23.11 | 100 | 22.66 | 100 | 23.10 | 100 | 22.60 |
| 110 | 23.11 | 110 | 22.67 | 110 | 23.10 | 110 | 22.62 |
| 120 | 23.12 | 120 | 22.68 | 120 | 23.11 | 120 | 22.63 |
| 130 | 23.13 | 130 | 22.69 | 130 | 23.11 | 130 | 22.65 |
| 140 | 23.13 | 140 | 22.70 | 140 | 23.11 | 140 | 22.66 |
| 150 | 23.14 | 150 | 22.71 | 150 | 23.11 | 150 | 22.68 |
| 160 | 23.15 | 160 | 22.72 | 160 | 23.11 | 160 | 22.69 |
| 170 | 23.15 | 170 | 22.72 | 170 | 23.12 | 170 | 22.71 |
| 180 | 23.16 | 180 | 22.74 | 180 | 23.12 | 180 | 22.72 |
| 190 | 23.16 | 190 | 22.74 | 190 | 23.12 | 190 | 22.73 |
| 200 | 23.17 | 200 | 22.75 | 200 | 23.12 | 200 | 22.74 |
| 210 | 23.17 | 210 | 22.76 | 210 | 23.12 | 210 | 22.75 |
| 220 | 23.18 | 220 | 22.77 | 220 | 23.13 | 220 | 22.76 |
| 230 | 23.18 | 230 | 22.78 | 230 | 23.13 | 230 | 22.77 |
| 240 | 23.19 | 240 | 22.79 | 240 | 23.13 | 240 | 22.78 |
| 250 | 23.19 | 250 | 22.80 | 250 | 23.13 | 250 | 22.79 |
| 260 | 23.20 | 260 | 22.81 | 260 | 23.13 | 260 | 22.80 |
| 270 | 23.20 | 270 | 22.82 | 270 | 23.14 | 270 | 22.81 |
| 280 | 23.21 | 280 | 22.83 | 280 | 23.14 | 280 | 22.82 |
| 290 | 23.21 | 290 | 22.84 | 290 | 23.14 | 290 | 22.83 |
| 300 | 23.22 | 300 | 22.84 | 300 | 23.14 | 300 | 22.84 |
| 310 | 23.20 | 310 | 22.82 | 310 | 23.07 | 310 | 22.76 |
| 320 | 23.14 | 320 | 22.69 | 320 | 22.92 | 320 | 22.62 |
| 330 | 23.06 | 330 | 22.54 | 330 | 22.76 | 330 | 22.48 |
| 340 | 22.97 | 340 | 22.37 | 340 | 22.60 | 340 | 22.35 |
| 350 | 22.89 | 350 | 22.17 | 350 | 22.46 | 350 | 22.22 |
| 360 | 22.80 | 360 | 22.09 | 360 | 22.32 | 360 | 22.10 |
| 370 | 22.73 | 370 | 22.00 | 370 | 22.20 | 370 | 21.99 |
| 380 | 22.66 | 380 | 21.94 | 380 | 22.09 | 380 | 21.90 |
| 390 | 22.60 | 390 | 21.86 | 390 | 21.98 | 390 | 21.81 |
| 400 | 22.54 | 400 | 21.80 | 400 | 21.89 | 400 | 21.73 |
| 410 | 22.49 | 410 | 21.75 | 410 | 21.81 | 410 | 21.66 |
| 420 | 22.44 | 420 | 21.71 | 420 | 21.73 | 420 | 21.66 |
| 430 | 22.40 | 430 | 21.67 | 430 | 21.66 | 430 | 21.54 |
| 440 | 22.36 | 440 | 21.65 | 440 | 21.59 | 440 | 21.49 |
| 450 | 22.32 | 450 | 21.62 | 450 | 21.53 | 450 | 21.44 |
| 460 | 22.29 | 460 | 21.60 | 460 | 21.48 | 460 | 21.40 |
| 470 | 22.25 | 470 | 21.58 | 470 | 21.43 | 470 | 21.36 |
| 480 | 22.23 | 480 | 21.57 | 480 | 21.39 | 480 | 21.32 |
| 490 | 22.20 | 490 | 21.56 | 490 | 21.35 | 490 | 21.29 |
| 500 | 22.18 | 500 | 21.55 | 500 | 21.32 | 500 | 21.25 |
| 510 | 22.16 | 510 | 21.54 | 510 | 21.28 | 510 | 21.22 |
| 520 | 22.14 | 520 | 21.53 | 520 | 21.26 | 520 | 21.20 |
| 530 | 22.12 | 530 | 21.53 | 530 | 21.24 | 530 | 21.15 |
| 540 | 22.10 | 540 | 21.52 | 540 | 21.23 | 540 | 21.15 |
| 550 | 22.09 | 550 | 21.51 | 550 | 21.20 | 550 | 21.13 |
| 560 | 22.08 | 560 | 21.51 | 560 | 21.19 | 560 | 21.12 |
| 570 | 22.07 | 570 | 21.50 | 570 | 21.17 | 570 | 21.10 |
| 580 | 22.06 | 580 | 21.50 | 580 | 21.16 | 580 | 21.09 |
| 590 | 22.05 | 590 | 21.50 | 590 | 21.15 | 590 | 21.08 |
| 600 | 22.05 | 600 | 21.49 | 600 | 21.15 | 600 | 21.07 |

Figure ：Time-temperature diagrams of NaAC·3H2O in dewar vessel.

Figure : Time-temperature diagrams of NaAC·3H2O in cup.

Table : Measured dataset of Na2SO3.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 22.77 | 0 | 22.45 | 0 | 22.85 | 0 | 22.64 |
| 10 | 22.79 | 10 | 22.45 | 10 | 22.85 | 10 | 22.63 |
| 20 | 22.80 | 20 | 22.45 | 20 | 22.85 | 20 | 22.63 |
| 30 | 22.80 | 30 | 22.45 | 30 | 22.86 | 30 | 22.64 |
| 40 | 22.81 | 40 | 22.46 | 40 | 22.87 | 40 | 22.64 |
| 50 | 22.81 | 50 | 22.47 | 50 | 22.88 | 50 | 22.65 |
| 60 | 22.82 | 60 | 22.48 | 60 | 22.89 | 60 | 22.65 |
| 70 | 22.83 | 70 | 22.49 | 70 | 22.89 | 70 | 22.66 |
| 80 | 22.83 | 80 | 22.50 | 80 | 22.89 | 80 | 22.66 |
| 90 | 22.84 | 90 | 22.51 | 90 | 22.90 | 90 | 22.66 |
| 100 | 22.85 | 100 | 22.52 | 100 | 22.89 | 100 | 22.67 |
| 110 | 22.85 | 110 | 22.53 | 110 | 22.89 | 110 | 22.67 |
| 120 | 22.86 | 120 | 22.54 | 120 | 22.89 | 120 | 22.68 |
| 130 | 22.86 | 130 | 22.55 | 130 | 22.88 | 130 | 22.68 |
| 140 | 22.87 | 140 | 22.56 | 140 | 22.88 | 140 | 22.69 |
| 150 | 22.87 | 150 | 22.57 | 150 | 22.88 | 150 | 22.69 |
| 160 | 22.88 | 160 | 22.57 | 160 | 22.88 | 160 | 22.70 |
| 170 | 22.89 | 170 | 22.58 | 170 | 22.88 | 170 | 22.70 |
| 180 | 22.89 | 180 | 22.59 | 180 | 22.88 | 180 | 22.71 |
| 190 | 22.90 | 190 | 22.60 | 190 | 22.88 | 190 | 22.71 |
| 200 | 22.90 | 200 | 22.61 | 200 | 22.88 | 200 | 22.71 |
| 210 | 22.91 | 210 | 22.62 | 210 | 22.88 | 210 | 22.71 |
| 220 | 22.91 | 220 | 22.62 | 220 | 22.88 | 220 | 22.71 |
| 230 | 22.92 | 230 | 22.63 | 230 | 22.89 | 230 | 22.71 |
| 240 | 22.92 | 240 | 22.64 | 240 | 22.89 | 240 | 22.71 |
| 250 | 22.92 | 250 | 22.64 | 250 | 22.89 | 250 | 22.71 |
| 260 | 22.93 | 260 | 22.65 | 260 | 22.89 | 260 | 22.71 |
| 270 | 22.93 | 270 | 22.66 | 270 | 22.89 | 270 | 22.71 |
| 280 | 22.94 | 280 | 22.67 | 280 | 22.89 | 280 | 22.71 |
| 290 | 22.94 | 290 | 22.67 | 290 | 22.89 | 290 | 22.71 |
| 300 | 22.94 | 300 | 22.68 | 300 | 22.89 | 300 | 22.71 |
| 310 | 22.98 | 310 | 22.69 | 310 | 22.96 | 310 | 22.73 |
| 320 | 23.18 | 320 | 22.79 | 320 | 23.17 | 320 | 22.92 |
| 330 | 23.24 | 330 | 22.87 | 330 | 23.34 | 330 | 23.08 |
| 340 | 23.34 | 340 | 22.92 | 340 | 23.48 | 340 | 23.20 |
| 350 | 23.41 | 350 | 23.01 | 350 | 23.58 | 350 | 23.29 |
| 360 | 23.45 | 360 | 23.05 | 360 | 23.66 | 360 | 23.35 |
| 370 | 23.46 | 370 | 23.08 | 370 | 23.71 | 370 | 23.40 |
| 380 | 23.46 | 380 | 23.13 | 380 | 23.76 | 380 | 23.44 |
| 390 | 23.46 | 390 | 23.16 | 390 | 23.79 | 390 | 23.47 |
| 400 | 23.46 | 400 | 23.19 | 400 | 23.81 | 400 | 23.50 |
| 410 | 23.46 | 410 | 23.22 | 410 | 23.83 | 410 | 23.53 |
| 420 | 23.46 | 420 | 23.24 | 420 | 23.84 | 420 | 23.55 |
| 430 | 23.46 | 430 | 23.26 | 430 | 23.85 | 430 | 23.57 |
| 440 | 23.46 | 440 | 23.27 | 440 | 23.86 | 440 | 23.58 |
| 450 | 23.46 | 450 | 23.28 | 450 | 23.87 | 450 | 23.59 |
| 460 | 23.47 | 460 | 23.30 | 460 | 23.87 | 460 | 23.60 |
| 470 | 23.47 | 470 | 23.31 | 470 | 23.88 | 470 | 23.61 |
| 480 | 23.48 | 480 | 23.32 | 480 | 23.88 | 480 | 23.61 |
| 490 | 23.48 | 490 | 23.33 | 490 | 23.87 | 490 | 23.62 |
| 500 | 23.49 | 500 | 23.34 | 500 | 23.86 | 500 | 23.62 |
| 510 | 23.50 | 510 | 23.35 | 510 | 23.86 | 510 | 23.63 |
| 520 | 23.50 | 520 | 23.35 | 520 | 23.85 | 520 | 23.63 |
| 530 | 23.51 | 530 | 23.36 | 530 | 23.84 | 530 | 23.63 |
| 540 | 23.52 | 540 | 23.37 | 540 | 23.84 | 540 | 23.64 |
| 550 | 23.52 | 550 | 23.37 | 550 | 23.84 | 550 | 23.64 |
| 560 | 23.53 | 560 | 23.37 | 560 | 23.84 | 560 | 23.64 |
| 570 | 23.53 | 570 | 23.38 | 570 | 23.83 | 570 | 23.65 |
| 580 | 23.53 | 580 | 23.38 | 580 | 23.83 | 580 | 23.65 |
| 590 | 23.54 | 590 | 23.38 | 590 | 23.83 | 590 | 23.65 |
| 600 | 23.54 | 600 | 23.38 | 600 | 23.82 | 600 | 23.65 |

Figure : Time-temperature diagrams of Na2S2O3 in dewar vessel.

Figure : Time-temperature diagrams of Na2S2O3 in cup.

Table : Measured dataset of Na2SO3·5H2O.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **D1-Time [s]** | **Temperature [°C]** | **D2-Time [s]** | **Temperature [°C]** | **C1-Time [s]** | **Temperature [°C]** | **C2-Time [s]** | **Temperature [°C]** |
| 0 | 22.31 | 0 | 22.84 | 0 | 22.59 | 0 | 23.57 |
| 10 | 22.33 | 10 | 22.87 | 10 | 22.65 | 10 | 23.57 |
| 20 | 22.34 | 20 | 22.89 | 20 | 22.70 | 20 | 23.57 |
| 30 | 22.35 | 30 | 22.93 | 30 | 22.74 | 30 | 23.58 |
| 40 | 22.37 | 40 | 22.96 | 40 | 22.78 | 40 | 23.58 |
| 50 | 22.38 | 50 | 22.99 | 50 | 22.80 | 50 | 23.58 |
| 60 | 22.39 | 60 | 23.02 | 60 | 22.83 | 60 | 23.59 |
| 70 | 22.41 | 70 | 23.04 | 70 | 22.85 | 70 | 23.59 |
| 80 | 22.42 | 80 | 23.06 | 80 | 22.87 | 80 | 23.60 |
| 90 | 22.43 | 90 | 23.08 | 90 | 22.89 | 90 | 23.60 |
| 100 | 22.44 | 100 | 23.09 | 100 | 22.91 | 100 | 23.60 |
| 110 | 22.46 | 110 | 23.11 | 110 | 22.92 | 110 | 23.61 |
| 120 | 22.47 | 120 | 23.12 | 120 | 22.94 | 120 | 23.61 |
| 130 | 22.48 | 130 | 23.13 | 130 | 22.95 | 130 | 23.62 |
| 140 | 22.49 | 140 | 23.14 | 140 | 22.97 | 140 | 23.62 |
| 150 | 22.50 | 150 | 23.15 | 150 | 22.98 | 150 | 23.62 |
| 160 | 22.52 | 160 | 23.16 | 160 | 22.99 | 160 | 23.63 |
| 170 | 22.53 | 170 | 23.17 | 170 | 23.00 | 170 | 23.63 |
| 180 | 22.54 | 180 | 23.17 | 180 | 23.01 | 180 | 23.64 |
| 190 | 22.55 | 190 | 23.18 | 190 | 23.03 | 190 | 23.64 |
| 200 | 22.56 | 200 | 23.18 | 200 | 23.04 | 200 | 23.64 |
| 210 | 22.57 | 210 | 23.19 | 210 | 23.05 | 210 | 23.65 |
| 220 | 22.58 | 220 | 23.19 | 220 | 23.06 | 220 | 23.65 |
| 230 | 22.59 | 230 | 23.19 | 230 | 23.06 | 230 | 23.65 |
| 240 | 22.60 | 240 | 23.19 | 240 | 23.07 | 240 | 23.66 |
| 250 | 22.61 | 250 | 23.20 | 250 | 23.08 | 250 | 23.66 |
| 260 | 22.62 | 260 | 23.20 | 260 | 23.09 | 260 | 23.66 |
| 270 | 22.63 | 270 | 23.21 | 270 | 23.10 | 270 | 23.67 |
| 280 | 22.64 | 280 | 23.21 | 280 | 23.10 | 280 | 23.67 |
| 290 | 22.65 | 290 | 23.22 | 290 | 23.11 | 290 | 23.67 |
| 300 | 22.66 | 300 | 23.22 | 300 | 23.12 | 300 | 23.67 |
| 310 | 22.65 | 310 | 23.18 | 310 | 23.03 | 310 | 23.52 |
| 320 | 22.38 | 320 | 23.05 | 320 | 22.85 | 320 | 23.08 |
| 330 | 22.15 | 330 | 22.86 | 330 | 22.63 | 330 | 22.72 |
| 340 | 22.00 | 340 | 22.69 | 340 | 22.41 | 340 | 22.49 |
| 350 | 21.84 | 350 | 22.53 | 350 | 22.23 | 350 | 22.32 |
| 360 | 21.72 | 360 | 22.39 | 360 | 22.06 | 360 | 22.19 |
| 370 | 21.61 | 370 | 22.27 | 370 | 21.90 | 370 | 22.08 |
| 380 | 21.54 | 380 | 22.18 | 380 | 21.77 | 380 | 21.99 |
| 390 | 21.49 | 390 | 22.11 | 390 | 21.65 | 390 | 21.92 |
| 400 | 21.45 | 400 | 22.04 | 400 | 21.55 | 400 | 21.86 |
| 410 | 21.41 | 410 | 21.99 | 410 | 21.46 | 410 | 21.81 |
| 420 | 21.38 | 420 | 21.94 | 420 | 21.37 | 420 | 21.76 |
| 430 | 21.35 | 430 | 21.90 | 430 | 21.29 | 430 | 21.73 |
| 440 | 21.32 | 440 | 21.86 | 440 | 21.23 | 440 | 21.69 |
| 450 | 21.31 | 450 | 21.83 | 450 | 21.16 | 450 | 21.66 |
| 460 | 21.29 | 460 | 21.80 | 460 | 21.11 | 460 | 21.64 |
| 470 | 21.28 | 470 | 21.77 | 470 | 21.06 | 470 | 21.62 |
| 480 | 21.26 | 480 | 21.75 | 480 | 21.01 | 480 | 21.60 |
| 490 | 21.25 | 490 | 21.73 | 490 | 20.97 | 490 | 21.59 |
| 500 | 21.25 | 500 | 21.71 | 500 | 20.94 | 500 | 21.57 |
| 510 | 21.24 | 510 | 21.69 | 510 | 20.91 | 510 | 21.56 |
| 520 | 21.23 | 520 | 21.68 | 520 | 20.89 | 520 | 21.55 |
| 530 | 21.22 | 530 | 21.66 | 530 | 20.86 | 530 | 21.55 |
| 540 | 21.22 | 540 | 21.65 | 540 | 20.85 | 540 | 21.55 |
| 550 | 21.22 | 550 | 21.64 | 550 | 20.83 | 550 | 21.54 |
| 560 | 21.21 | 560 | 21.63 | 560 | 20.82 | 560 | 21.54 |
| 570 | 21.21 | 570 | 21.62 | 570 | 20.81 | 570 | 21.54 |
| 580 | 21.21 | 580 | 21.62 | 580 | 20.80 | 580 | 21.54 |
| 590 | 21.21 | 590 | 21.61 | 590 | 20.80 | 590 | 21.54 |
| 600 | 21.21 | 600 | 21.61 | 600 | 20.79 | 600 | 21.54 |

Figure : Time-temperature diagrams of Na2S2O3·5H2O in dewar vessel.

Figure : Time-temperature diagrams of Na2S2O3·5H2O in cup.

References

1. [1] T. Wagner, “Calorimetry meets solvation – how to quantify dissolutions in detail,” *CHEMKON*, vol. 29, no. 5, pp. 382–386, 2022.
2. [2] T. Wagner, “Calorimetry is Now Faster, Easier and More Transparent Than Ever,” *CHEMKON*, vol. 28, no. 5, pp. 180–186, 2021.
3. [3] *Coffee Cup Calorimeter Heat Loss Correction*, 2016.
4. [4] R. H. Petrucci, *General chemistry*: *Principles and modern applications*, Pearson/Prentice Hall, Upper Saddle River N.J., 2007.
5. [5] D. A. Johnson, *Metals and chemical change*, Royal Society of Chemistry, Cambridge, 2002.
6. [6] J. D. Dunitz, “Weak Intermolecular Interactions in Solids and Liquids,” *Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals*, vol. 279, no. 1, pp. 209–218, 1996.
7. [7] D. W. Bolen and M. M. Santoro, “Unfolding free energy changes determined by the linear extrapolation method. 2. Incorporation of delta G degrees N-U values in a thermodynamic cycle,” *Biochemistry*, vol. 27, no. 21, pp. 8069–8074, 1988.
8. [8] S. S. Zumdahl and S. A. Zumdahl, *Chemistry*: *An atoms first approach*, Brooks/Cole CENGAGE Learning, Bellmont CA, 2012.
9. [9] I. D. Brown, *The chemical bond in inorganic chemistry*: *The bond valence model / I. David Brown*, Oxford University Press, Oxford, 2002 (2006 printing).
10. [10] K. W. Frese, “Calculation of Gibbs hydration energy with the ion-dielectric sphere model,” *The Journal of Physical Chemistry*, vol. 93, no. 15, pp. 5911–5916, 1989.
11. [11] C. H. Yoder, “Geochemical applications of the simple salt approximation to the lattice energies of complex materials,” *American Mineralogist*, vol. 90, 2-3, pp. 488–496, 2005.
12. [12] R. L. Montgomery, R. A. Melaugh, C.-C. Lau et al., “Determination of the energy equivalent of a water solution calorimeter with a standard substance,” *The Journal of Chemical Thermodynamics*, vol. 9, no. 10, pp. 915–936, 1977.
13. [13] A. A. Merdaw, A. O. Sharif, and G. Derwish, “Mass transfer in pressure-driven membrane separation processes, Part II,” *Chemical Engineering Journal*, vol. 168, no. 1, pp. 229–240, 2011.