Lab 20. Enthalpy Change of Solution: How Can Chemists Use the Properties of a Solute to Predict If an Enthalpy Change of Solution Will Be Exothermic or Endothermic?

Introduction

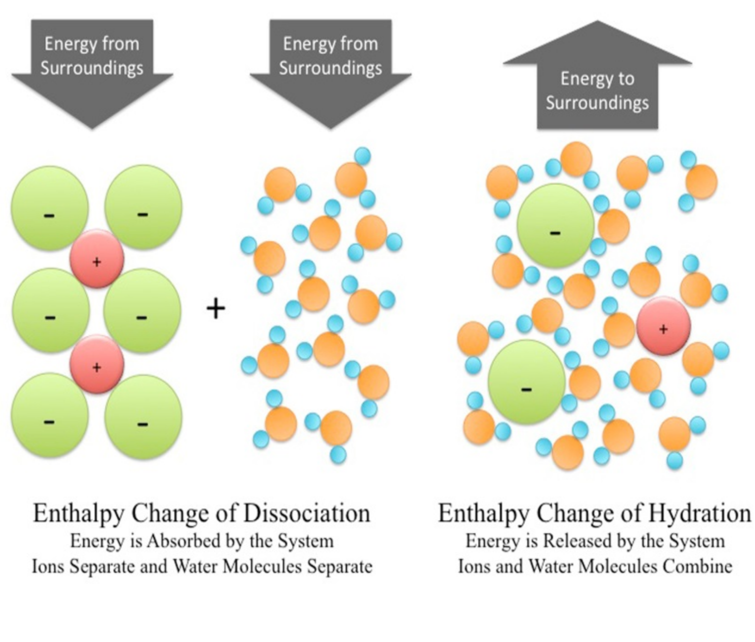
Thermodynamics is the study of energy changes in a system. Thermodynamics is an important field of study in chemistry because energy changes occur during chemical reactions, when solutes are dissolved in solvents, and when matter goes through a change of state. Chemists often describe the energy changes that take place in these situations in terms of heat content. *Enthalpy* is a measure of the heat content of a system. The transfer of heat into or out of a system results in a change in enthalpy. This change in the heat content of a system is symbolized as ΔH (delta H). The unit of measurement for an enthalpy change is kilojoules per mole (kJ/mol).

The enthalpy change that occurs when a solute is dissolved in water is called the heat of solution or the *enthalpy change of solution* ($\Delta H_{solution}$). The enthalpy change of solution is equal in magnitude to the heat energy lost from or gained by the surroundings. When heat energy is lost from the system and gained by the surroundings, the enthalpy change of solution is described as *exothermic*. An *endothermic* enthalpy change of solution, in contrast, occurs when the system gains heat energy from the surroundings.

The overall energy change that occurs when a solute is dissolved in water (i.e., the $\Delta H_{solution}$) is the result of two key processes. First, an input of energy breaks the attractive forces holding the particles in the solute together and disrupts the hydrogen bonds holding the water molecules together. The system *gains* energy and the surroundings *lose* energy during this process. For the purposes of this investigation, this change in energy will be called the *enthalpy change of dissociation* ($\Delta H_{dissociation}$). Second, energy is released as attractive forces form between the particles of the solute and the molecules of water. The system *loses* energy and the surroundings *gain* energy during this process. The energy change that occurs during this process is called the *enthalpy change of hydration* ($\Delta H_{hydration}$). An illustration of the energy inputs and outputs associated with dissolution of an ionic compound is provided in Figure L20.1.

FIGURE L20.1

The dissociation process and hydration process that take place when an ionic compound dissolves in water



As described earlier, the dissolution of a solute involves both a gain and a loss of energy, and the $\Delta H_{solution}$ of a solute can be either endothermic or exothermic depending on the net amount of energy that is lost from or gained by the system. The net energy change of the system will depend, in part, on the unique properties of the solute. Solutes can be composed of different types of particles, and attractive forces hold these particles together. The nature and strength of these attractive forces will influence the amount of energy that is required to break apart the solute. In addition, the particles that make up a solute will differ in terms of the strength of their electrical charge. Some solute particles, as a result, will attract water molecules better than others. The strength of attraction that exists between solute particles and water molecules will influence the amount of energy that is released when the solute particles and the water molecules combine. The physical and chemical properties of the solute, as a result, will affect the $\Delta H_{solution}$.

In this investigation, you will be given five different ionic compounds. You will then determine if the $\Delta H_{solution}$ for each ionic compound is endothermic or exothermic by mixing the solute with water and measuring the resulting temperature change. Next, you will use a table of $\Delta H_{dissociation}$ and $\Delta H_{hydration}$ values to develop a rule that you can use to predict if the $\Delta H_{solution}$ of other ionic compounds will be endothermic or exothermic. The $\Delta H_{dissociation}$ values reflect the amount of energy needed to separate the ions in the solute and the amount of energy needed to disrupt the attractive forces between the water molecules. The $\Delta H_{hydration}$ values reflect the energy that is released when ion-dipole forces form between the individual ions and the water molecules. You will then be given an opportunity to test your rule with two other ionic compounds to determine if you can use it to make accurate predictions.

Your Task

Develop a rule that chemists can use to determine if the enthalpy change of solution ($\Delta H_{solution}$) for a given ionic compound will be endothermic or exothermic based on the properties of the solute.

The guiding question for this investigation is, **How can chemists use the properties of a solute to predict if an enthalpy change of solution will be exothermic or endothermic?**

Materials

You may use any of the following materials during this investigation:

Consumables	Equipment
• Calcium chloride, $CaCl_2$, 5 grams • Cesium chloride, CsCl, 5 grams • Lithium chloride, LiCl, 5 grams • Potassium chloride, KCl, 5 grams • Sodium chlorate, $NaClO_4$, 5 grams • Sodium chloride, NaCl, 5 grams • Sodium iodide, NaI, 5 grams • Distilled water	• 2 polystyrene cups (or a calorimeter) • Thermometer (or temperature probe and sensor interface) • Graduated cylinder (25 ml) • 3 beakers (each 250 ml) • Stirring rod • Electronic or triple beam balance • Timer or stopwatch • Support stand and ring clamp • Chemical scoop • Weighing paper or dishes

Safety Precautions

Follow all normal lab safety rules. Lithium chloride, calcium chloride, cesium chloride, sodium chlorate, and sodium iodide are all moderately toxic by ingestion and are tissue irritants. Your teacher will explain relevant and important information about working with the chemicals associated with this investigation. In addition, take the following safety precautions:

- Wear indirectly vented chemical-splash goggles and chemical-resistant gloves and apron while in the laboratory.
- Handle all glassware with care.
- Wash your hands with soap and water before leaving the laboratory.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

The first step in developing your rule is to determine if the $\Delta H_{solution}$ for LiCl, $CaCl_2$, KCl, NaCl, and CsCl is endothermic or exothermic. To accomplish this step, you will need to dissolve each ionic compound in water and measure the resulting temperature change using a calorimeter. A calorimeter is an insulated container that is designed to prevent heat loss to the atmosphere. A simple calorimeter can be made from two polystyrene cups, a support stand, and a ring clamp (see Figure L20.2). Once you have set up a simple calorimeter, you must determine what type of data you need to collect, how you will collect the data, and how you will analyze the data.

To determine *what type of data you need to collect*, think about the following questions:

- What type of measurements or observations will you need to record during each test?
- How often will you need to make these measurements or observations?

To determine *how you will collect the data*, think about the following questions:

- How much water will you use in the calorimeter?
- Will the same amount of water be used for each test?
- How much of each ionic compound will you need to use?
- Will you need to use the same amount of each ionic compound for each test? If so, does it need to be the same amount in terms of mass or in terms of moles?
- What will you do to reduce measurement error?
- How will you keep track of the data you collect and how will you organize it?

To determine *how you will analyze the data*, think about the following questions:

- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

FIGURE L20.2

A simple calorimeter

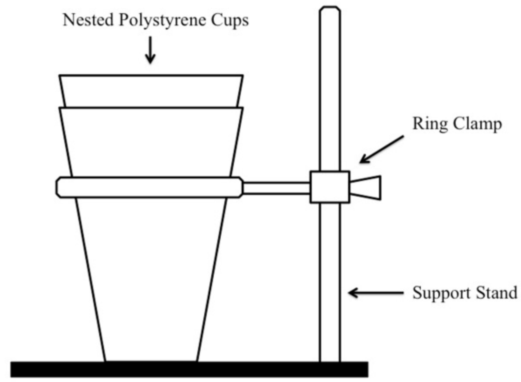


TABLE L20.1

$\Delta H_{dissociation}$ and $\Delta H_{hydration}$ values for the ionic compounds used in this investigation

Ionic compound	$\Delta H_{dissociation}$ (kJ/mol)*	$\Delta H_{hydration}$ (kJ/mol)
LiCl	853	–883
$CaCl_2$	2,258	–2378
KCl	715	–685
NaCl	788	–784
CsCl	657	–639
$NaClO_4$	658	–644
NaI	693	–701

* This value reflects the energy required to break apart the ions in the solute and the energy required to disrupt the hydrogen bonds between the water molecules.

Once you have carried out your series of tests, your group will need to develop your rule. Table L20.1 provides the $\Delta H_{dissociation}$ and $\Delta H_{hydration}$ values for each ionic compound. Positive values indicate that the energy is being absorbed by the system, and negative values indicate that energy is being released by the system. As you develop your rule, think about how you could present it as a mathematical equation.

The last step is to test your rule. To accomplish this goal, you will need to determine if you can use your rule to make accurate predictions. You should, in other words, be able to use your rule to predict if the $\Delta H_{solution}$ of $NaClO_4$ and NaI will be exothermic or endothermic. If you are able to make accurate predictions about the $\Delta H_{solution}$ for these two ionic compounds, then you will be able to generate the evidence you need to convince others that the rule that you developed is valid.

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

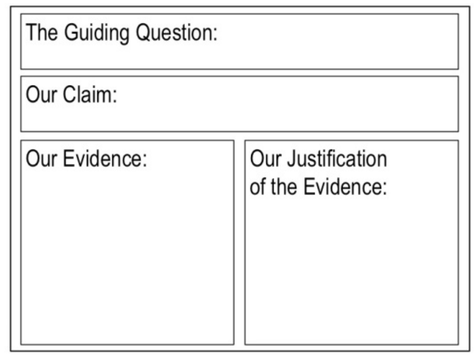
- the importance of defining the system under study and then using a model to make sense of it,
- the importance of tracking how matter and energy move into and within a system,
- the difference between observations and inferences in science, and
- the difference between laws and theories in science.

Initial Argument

Once your group has finished collecting and analyzing your data, you will need to develop an initial argument. Your argument must include a *claim*, which is your answer to the guiding question. Your argument must also include *evidence* in support of your claim. The evidence is your analysis of the data and your interpretation of what the analysis means. Finally, you must include a *justification* of the evidence in your argument. You will therefore need to use a scientific concept or principle to explain why the evidence that you decided to use is relevant and important. You will create your initial argument on a whiteboard. Your whiteboard must include all the information shown in Figure L20.3.

FIGURE L20.3

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group stays at the lab station to share that group's argument, while the other members of the group go to the other lab stations one at a time to listen to and critique the arguments developed by their classmates. The goal of the argumentation session is not to convince others that your argument is the best one; rather, the goal is to identify errors or instances of faulty reasoning in the initial arguments so these mistakes can be fixed. You will therefore need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included in each argument that you see. To critique an argument, you might need more information than what is included on the whiteboard. You might, therefore, need to ask the presenter one or more follow-up questions, such as:

- What did your group do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- What did your group do to analyze the data, and why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your group's analysis? How do you know that your interpretation of the analysis is appropriate?
- Why did your group decide to present your evidence in that manner?
- What other claims did your group discuss before deciding on that one? Why did you abandon those alternative ideas?
- How confident are you that your group's claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your original argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most valid or acceptable answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections that provide answers to the following questions:

1. What question were you trying to answer and why?
2. What did you do during your investigation and why did you conduct your investigation in this way?
3. What is your argument?

Your report should answer these questions in two pages or less. The report must be typed and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!