**Designing a Hand Warmer**

Breaking bonds and particle attractions absorb energy from the surroundings, while forming new bonds and particle attractions release energy to the surroundings. When an ionic solid dissolves in water, ionic bonds between cations and anions in the solid and hydrogen bonds between water molecules are broken, and new attractions between water molecules and anions, and water molecules and cations are formed. The amount of energy needed to break these bonds and to form new ones depends on the chemical properties of the particular cations and anions. Therefore, when some ionic solids dissolve, more energy is required to break the cation-anion bonds than is released in forming new water-ion attractions, and the overall process absorbs energy in the form of heat. When other ionic compounds dissolve, the opposite is true, and the bond making releases more energy than the bond breaking absorbs, and the overall process releases heat. When heat is absorbed, the enthalpy change is endothermic and its value is positive. When heat is released, the change is exothermic and the value of ᐃH is negative.

Hand warmers are small packets that people put inside their gloves on cold days to keep their fingers warm. They are very popular with people who work outside in winter or do winter sports. One type of hand warmer contains water in one section of the packet and a soluble substance in another section. When the packet is squeezed the water and the soluble substance are mixed, the solid dissolves, and the packet becomes warm. In this experiment you will learn how a hand warmer works and design an effective, safe, and inexpensive hand warmer. You will carry out an experiment to determine which substances, in what amounts, to use in order to make a hand warmer that increases in temperature by 20 °C (but no more) as quickly as possible, has a volume of about 50 mL, costs as little as possible to make, and uses chemicals that are safe and as environmentally friendly as possible.

You will collect data that will allow you to calculate the change of enthalpy of solution occurring in aqueous solution using a calorimeter. A calorimeter is a container used to determine the enthalpy change that occurs during a process. Calorimetry is an important technique in chemistry, but for classroom experiments, a coffee cup calorimeter is sufficient for rough measurements. This experiment will give you experience using a calorimeter so that you can determine which ionic solid is best to use in a hand warmer. It will also allow you to calibrate your calorimeter with a process that supplies a known amount of heat. This calibration process allows you to determine the amount of heat the calorimeter itself absorbs as the temperature of the materials inside it change, a value known as a calorimeter constant, Ccal.

**Calorimeter Calibration Procedure**:

Place 100.0 mL of water in a clean, dry 150 mL beaker. Heat the water with occasional stirring to about 50 °C. Remove the beaker from the hot plate and place on the lab table. Place another 100.0 mL of room temperature water in the clean, dry calorimeter. Place a magnetic stir bar in the calorimeter, place in on a magnetic stirrer and begin stirring the water making sure there is no splashing. Measure the temperature of the hot water and cold water and record, then immediately pour the entire hot water sample into the calorimeter and quickly put on the cover. Wait 15 seconds and then take a temperature reading. Repeat the temperature measurement twice more, every 15 seconds.

**Calibration Constant Determination**:

According to the first law of thermodynamics, energy can only be changed from one form to another or transferred from one system to another. The temperature change observed when water or any substance changes temperature can be a result of a transfer of energy from the substance to the surroundings (temperature of the substance decreases) or the surroundings to the substance (temperature of the substance increases). When hot and cold water are mixed, the hot water transfers some of its thermal energy to the cold water. The law of conservation of energy dictates that the amount of thermal energy lost (or enthalpy change) by the hot water, qhot, is equal to the enthalpy change of the cold water, *q*cold, but opposite in sign, so *q*hot = - *q*cold. The enthalpy change for any substance is directly related to the mass of the substance, **m**; the specific heat capacity, **s**; and the temperature change, ∆T. The relationship is expressed mathematically in the equation:  *q* = ms ∆T. (The specific heat capacity of water is 4.184 J/ °C g.)

1. Separately, calculate the enthalpy change of the cold water and the hot water using the equation *q* = ms ∆T and assume that the density of water is exactly 1 g/mL.

2. These amounts are not equal because the calorimeter absorbs some of the thermal energy transferred by the hot water. So, under the real conditions in the lab, the law of conservation of energy equation becomes: *q*hot = - (*q*cold + *q*cal), where *q*cal is the enthalpy change of the calorimeter.

3. The calorimeter constant, Ccal, is the heat absorbed by the calorimeter per degree of temperature change, Ccal = *q*cal/∆Tcal. Assuming the starting temperature of the calorimeter is the same as that of the cold water, calculate the calorimeter constant in J/° C.

The solid and water, as a mixture, have a certain amount of internal energy as a function of the bonds that exist in the solid and the water. The solution produced as a result of the dissolving has a different amount of internal energy than the water and solid did because the arrangement of particles and the bonds and attractions between the particles in the solution are different bonds and particulate attractions than the arrangement of particles and the bonds and attractions between the particles in the solid and water. The difference in energy, *q*solution, is the reason for the difference in the thermal energy of the two systems (solid and pure water versus solution), represented *q*rxn, where –*q*soln = *q*rxn. Since the calorimeter also experiences an enthalpy change, the relationship is adjusted where *q*soln = - (*q*rxn + CcalᐃT). The heat of reaction is: *q*rxn = ms ᐃT, where m is the total mass of the solution, s is the specific heat of the solution and ᐃT is the temperature change of the solution. {We will assume that the heat capacity of the solution is the same as pure water.}

Suggested Materials:

Ammonium Chloride Styrofoam Cups Calcium Chloride Graduated Cylinder Sodium Acetate Hot Plate Sodium Chloride Magnetic Stirrer and Stir Bar Lithium Chloride Thermometer Sodium Carbonate Timer Distilled Water Weighing Trays Balance Beaker

**Guided-Inquiry Design and Procedure**

1. Calorimetry Procedure:

a. What data is needed to calculate the enthalpy change for a reaction?

b. Identify the variables that will influence the data.

c. What variables should be controlled during the procedure?

d. What are the dependent and independent variables in a calorimetry experiment?

2. Choose three ionic salts, and design an experiment to determine the heat of solution for each solid.

a. The hand warmer must contain about 5-10 g of an ionic solid and about 40 mL of water.

b. The hand warmer reaction must increase the temperature of the resulting solution by at least 20 °C.

c. The solid should be safe and economical.

Cost Information:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Salt | NH4Cl | CaCl2 | LiCl | NaC2H3O2 | Na2CO3 | NaCl |
| $/Kilogram | 21.90 | 10.80 | 68.30 | 27.30 | 5.95 | 4.25 |

**Calculations**:

Determine the calorimeter constant, Ccal for your calorimeter.

Calculate *q*soln and *q*rxn for all three solids you tested in preparing your hand warmer.

Using your values of *q*soln, calculate the enthalpy in units of kilojoules per mole for each of the three solids you tested.

Based on the cost information provided to you, select which chemical you believe will make the most cost-effective hand warmer. Your hand warmer needs to increase in temperature by 20 °C. Calculate the amount of the compound you selected that would be required for a hand warmer that meets this requirement.

**Summary/Analysis**:

Describe all of the factors you considered and explain your rationale for choosing one chemical over the others you studied. State your choice and the amount of substance needed, followed by evidence relating to temperature change, cost and safety. Include evidence that supports your claim

**Error Analysis:**

Describe possible sources of error that could affect the accuracy of your calculated value for the amount of solid in your hand warmer and the effect they would have on the temperature change.