Hot Packs, Cold Packs, and Heats of Solution

INSTRUCTOR RESOURCES

The CCLI Initiative

Learning Objectives

- use the ***MicroLAB*** interface to measure the heats of solution (ΔH_{soln} , in kJ/mol) of several salts.
- calculate the heats of formation (ΔH_f , in kJ/mol) of single aqueous ions.
- predict the heats of solution of additional salts.
- design a hot pack and a cold pack for specified temperature changes.

Procedure Overview

- the ***MicroLAB*** interface is used to measure temperature changes in a Styrofoam cup calorimeter.
- ΔT values are determined graphically for the dissolution of four salts.
- ΔH_{soln} calculated for each salt.
- ΔH_f calculated for the ions in each of the four salts.
- ΔH_f values for the ions used to find ΔH_{soln} for two additional salts.
- a cold pack designed using NH_4NO_3, and a hot pack designed using $MgSO_4$.

Name ______________________________ Section __________ Date ____________________

HOT PACKS, COLD PACKS, AND HEATS OF SOLUTION

Report Sheet

Measurement of ΔH_{soln} (data and calculations):

Salt	Mass (g)	T_i (°C)	T_f (°C)	ΔT(°C)	ΔH_{soln}(kJ/mol)
$MgSO_4$	________	________	________	________	________
K_2SO_4	________	________	________	________	________
KNO_3	________	________	________	________	________
NH_4NO_3	________	________	________	____	________

Sample calculation for:

ΔH_{soln} for $MgSO_4$ (kJ/mol)

ΔH_{soln} for K_2SO_4 (kJ/mol)

ΔH_{soln} for KNO_3 (kJ/mol)

ΔH_{soln} for NH_4NO_3 (kJ/mol)

Name _______________________________ Section __________ Date ____________________

HOT PACKS, COLD PACKS, AND HEATS OF SOLUTION

Report Sheet (page 2)

Calculated ΔH_f of ions and ΔH_{soln} of salts:

Ions	ΔH_f (kJ/mol)	Salts	ΔH_{soln} (kJ/mol)
K^+	- 251.2	$Mg(NO_3)_2$	____________
Mg^{2+}	____________	$(NH_4)_2SO_4$	____________
NH_4^+	____________		
SO_4^{2-}	____________		
NO_3^-	____________		

Calculations for

ΔH_f for Mg^{2+}:

ΔH_f for NH_4^+:

ΔH_f for (SO_4^{2-})

ΔH_f for NO_3^-

ΔH_f for $Mg(NO_3)_2$

ΔH_f for $(NH_4)_2SO_4$

Name ______________________________ Section __________ Date ____________________

HOT PACKS, COLD PACKS, AND HEATS OF SOLUTION

Report Sheet (Page 3)

Design of cold and hot packs:

Cold pack:
Calc. grams of NH_4NO_3:

Calc. grams of water:

Hot Pack:
Calculate grams of $MgSO_4$:

Calculate grams of water:

Cold Pack	**Hot Pack**
________ g NH_4NO_3 __________ g water	__________ g $MgSO_4$ ___________ g water

Name ______________________________ Section __________ Date ____________________

COLD PACKS, HOT PACKS, AND HEATS OF SOLUTION

Questions/Problems

1. Look up the literature value for the heat of solution of each of the four salts that you studied. Determine the percent error between your value and the literature value. Provide some possible reasons for any differences that are observed.

2. Obtain information on costs of the chemicals used in the hot pack and cold pack that you designed and determine the total materials cost to produce these items. Compare these costs to the actual costs of hot packs and cold packs available in local stores.

HOT PACKS, COLD PACKS AND HEATS OF SOLUTION

Tips and Traps

1. Stirring is critical in this lab.
2. Stirring should be vigorous without splashing.
3. Magnetic stirrers may cause interference with the computers. If so, manual stirring will be necessary.
4. Salts must be thoroughly dried before lab, and kept in tight containers to prevent uptake of additional moisture.
5. Make sure that the salts are added to the water in such a manner that they do not stick to the sides of the Styrofoam cup.
6. The thermistor must be *in* the solution without touching the bottom of the container or the magnetic stir bar.
7. An alternative method for supporting the foam cups is a suitable iron ring (3-inch).
8. If temperature drift is observed after salt addition, extrapolation of temperature to the time of mixing will provide a more reliable T_f value.
9. You need a cover for the foam cups. There are many alternatives; two are suggested below:
   a. a plastic coffee cup lid.
   b. a foam square, 3.5" x 3.5" x 0.5" with a hole in the middle for the thermistor. A rubber band or small piece of rubber hose around the thermistor will prevent it from slipping through the foam block or the coffee cup cover.
10. The heat capacity for the calorimeter can be experimentally determined if so desired. A common method is based on the heat produced on mixing known amounts of HCl and NaOH.
11. In designing the hot pack and cold pack, the assumption of 4.18 J/g°C for the *solution* introduces some error because the solution has a different specific heat than pure water.

HOT PACKS, COLD PACKS AND HEATS OF SOLUTION

Sample Data (Page 1)

Measurement of ΔH_{soln} (data and calculations):

Salt	Mass (g)	T_i (°C)	T_f (°C)	ΔT (°C)	ΔH_{soln}(kJ/mol)
$MgSO_4$	5.00	20.1	27.5	7.4	−82
K_2SO_4	5.00	19.8	18.1	−1.7	27
KNO_3	5.00	20.0	16.2	−3.8	36
NH_4NO_3	5.00	20.0	16.4	−3.6	27

Calculations for each of the four salts:

$$\Delta H_{soln}\ (MgSO_4) = -\frac{(7.4°C)\ (120\ g/mol)\ (463\ J/°C)}{(5.00\ g)\ (1000\ J/kJ)}$$

$$= -82\ kJ/mol$$

$$\Delta H_{soln}\ (K_2SO_4) = -\frac{(-1.7°C)\ (174\ g/mol)\ (463\ J/°C)}{(5.00\ g)\ (1000\ J/kJ)}$$

$$= 27.4\ kJ/mol$$

$$\Delta H_{soln}\ (KNO_3) = -\frac{(-3.8°C)\ (101\ g/mol)\ (463\ J/°C)}{(5.00\ g)\ (1000\ J/kJ)}$$

$$= 36\ kJ/mol$$

$$\Delta H_{soln}\ (NH_4NO_3) = -\frac{(-3.6°C)\ (80\ g/mol)\ (463\ J/°C)}{(5.00\ g)\ (1000\ J/kJ)}$$

$$= 27\ kJ/mol$$

HOT PACKS, COLD PACKS, AND HEATS OF SOLUTION

Sample Data (page 2)

Calculated ΔH_f of ions and ΔH_{soln} of salts:

Ions	ΔH_f (kJ/mol)	Salts	ΔH_{soln} (kJ/mol)
K^+	−251.2	$Mg(NO_3)_2$	−86
Mg^{2+}	−464	$(NH_4)_2SO_4$	10
NH_4^+	−133		
SO_4^{2-}	−904		
NO_3^-	−206		

Sample calculations: (a) ΔH_f for Mg^{2+}, (b) ΔH_{soln} for $Mg(NO_3)_2$

(a) First calculate $\Delta H_f\ (SO_4^{2-})$

$$\Delta H_f\ (SO_4^{2-}) = \Delta H_{soln}\ (K_2SO_4) + \Delta H_f^\circ\ (K_2SO_4) - 2\ \Delta H_f\ (K^+)$$

$$= [(27) + (-1433) - 2(-251)]\ \text{kJ/mol}$$

$$= -904\ \text{kJ/mol}$$

Next calculate $\Delta H_f\ (Mg^{2+})$

$$\Delta H_f\ (Mg^{2+}) = \Delta H_{soln}\ (MgSO_4) + \Delta H_f^\circ\ (MgSO_4) - \Delta H_f\ (SO_4^{2-})$$

$$= [(-82) + (-1285) - (-904)]\ \text{kJ/mol}$$

$$= -464\ \text{kJ/mol}$$

(b) $$\Delta H_{soln}\ (Mg\ (NO_3)_2) = \Delta H_f\ (Mg^{2+}) + 2\ \Delta H_f\ (NO_3^-) - \Delta H_f^\circ\ (Mg\ (NO_3)_2)$$

$$= [(-464) + 2(-206) - (-790)\ \text{kJ/mol}$$

$$= -86\ \text{kJ/mol}$$

HOT PACKS, COLD PACKS, AND HEATS OF SOLUTION

Sample Data (page 2 continued)

Calculate $\Delta H_f\ (NO_3^-)$

$$= \Delta H_{soln}\ (KNO_3) + \Delta H_f^\circ\ (KNO_3) - \Delta H_f\ (K^+)$$

$$= [(36) + (-492.7) - (-251)\ \text{kJ/mol}$$

$$= -206\ \text{kJ/mol}$$

Calculate $\Delta H_f\ (NH_4^+)$

$$= \Delta H_{soln}\ (NH_4NO_3) + \Delta H_f^\circ\ (NH_4NO_3) - \Delta H_f\ (NO_3^-)$$

$$= [(27) + (-365.6) - (-206)\ \text{kJ/mol}$$

$$= -133\ \text{kJ/mol}$$

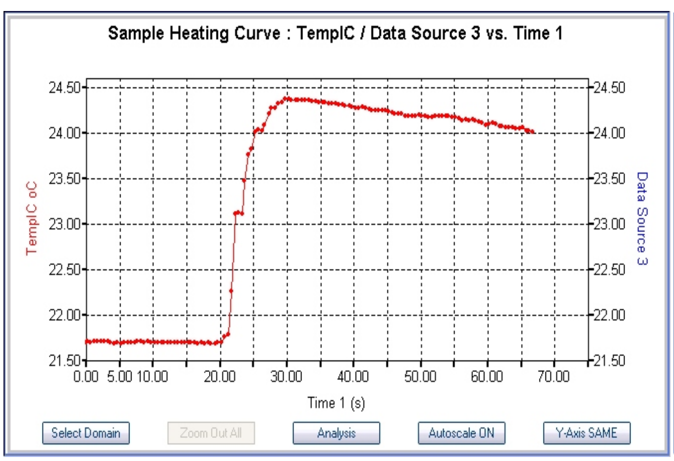
Calculate $\Delta H_{soln}\ ((NH_4)SO_4)$

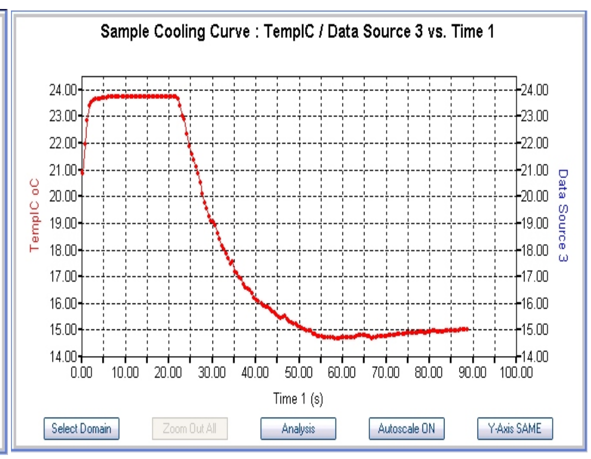
$$= 2 \text{ X } \Delta H_{soln}\ (NH_4^+) + \Delta H_f^\circ\ (SO_4^-) - \Delta H_f\ ((NH_4)SO_4)$$

$$= [2 \text{ X } (-133) + (-904) - (-1179.5)\ \text{kJ/mol}$$

$$= 10\ \text{kJ/mol}$$

Sample *MicroLAB* heating and cooling screens





HOT PACKS, COLD PACKS, AND HEATS OF SOLUTION

Sample Data (page 3)

Design of cold and hot packs:

Cold Pack	Hot Pack
65 g NH_4NO_3 335 g water	90 g $MgSO_4$ 310 g water

Cold pack:

(NH_4NO_3)

$$\frac{(4.18\ \text{J/g°C})\ (400\ \text{g})\ (13\text{°C})\ (80\ \text{g/mol})}{(27\ \text{kJ/mol})\ (1000\ \text{J/kJ})}$$

$$= 65\ \text{g}\ NH_4NO_3$$

(water) $400 - 65 = 335\ \text{g}\ H_2O$

Hot pack:

($MgSO_4$)

$$\frac{(4.18\ \text{J/g°C})\ (400\ \text{g})\ (37\text{°C})\ (120\ \text{g/mol})}{(82\ \text{kJ/mol})\ (1000\ \text{J/kJ})}$$

$$= 90\ \text{g}\ MgSO_4$$

(water) $400 - 90 = 310\ \text{g}\ H_2O$

COLD PACKS, HOT PACKS, AND HEAT OF SOLUTION

Suggested Answers to Questions/Problems

1. Look up the literature value for the heat of solution of each of the four salts that you studied. Determine the percent error between your value and the literature value. Provide some possible reasons for any differences that are observed.

Heats of Solution (from Lange - Handbook of Chemistry)

Compound	ΔH_{soln}	*Your Value*	*Difference*	*% error*
$MgSO_4$	**−84.9 kJ/mol**			
K_2O_4	**+26.7 kJ/mol**			
KNO_3	**+35.6 kJ/mol**			
NH_4NO_3	**+26.4 kJ/mol**			

1. ***Heat of solution varies with extent of dilution.***
2. ***The number of significant figures on measured temperature changes as a function of the care in probe calibration.***
3. ***Calorimeter heat capacity used is an average value, which will vary somewhat with each salt.***

2. Obtain information on costs of the chemicals used in the hot pack and cold pack that you designed and determine the total materials cost to produce these items. Compare these costs to the actual costs of hot packs and cold packs available in local stores.

Approximate material costs:

Cold Pack - $0.30 (based on ammonium nitrate at $8/lb)

Hot Pack - $0.38 (based on magnesium sulfate at $10/lb)

Actual costs:

Check local sporting goods stores.

HOT PACKS, COLD PACKS AND HEATS OF SOLUTION

Laboratory Preparation (per student station)

Equipment

- temperature probe
- ring stand
- utility clamp
- two foam cups (nested into a 400 ml beaker to form a calorimeter)
- cover for foam cup
- magnetic stirrer and stir bar
- 100 ml graduated cylinder
- MicroLab interface
- ice (for calibration)
- hot water (for calibration)

Supplies

- weighing paper or weighing boat

Chemicals

Each of these salts should be dried. On the morning of the lab, heat them in the oven in a beaker covered with a watch glass for 2 hours at the temperature indicated. Stir frequently to break up the material and obtain complete removal of unwanted water. Keep in tightly capped containers thereafter. Make a set of separate containers for each lab section.

Per pair of students

- 12 g $MgSO_{4(s)}$ (-6 H_2O @ 150 °C, mp 1124 °C, heat at 155 °C)
- 12 g $K_2SO_{4(s)}$ (mp 1069 °C, heat at 110 °C)
- 12 g $KNO_{3(s)}$ (mp 334 °C, heat at 110 °C)
- 12 g $NH_4NO_{3(s)}$ (mp 169.6 °C, heat at 110 °C)

Safety and Disposal

- make sure students wear eye protection at all times.
- all resulting solutions may be flushed down the drain with plenty of water.