VALENCIA COLLEGE

Experiment 8
Calorimetry

Version 5
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Adapted from Emily Lesher, Ph.D.[1] and Michael W. Vannatta, Ph.D. et al.[2]

The heat capacity of a Vienna sausage is determined and related to the amount of heat needed to treat frostbite. Several ionic compounds will be tested to determine a possible heat-generating process for a heat pack, and the selected ionic compound will be studied.

Objectives

- Measure, calculate, and correctly use the terms heat, temperature, specific heat, reaction enthalpy, endothermic reaction, and exothermic reaction.
- Understand the relationship between heat and specific heat capacity.
- Understand the relationship between enthalpy and heat.
- Calculate the amount of heat needed to heat a portion of a hand, and set up a dissolution reaction that will deliver that amount heat.

Learning Outcomes

Students will be able to:

- Identify reactions as exothermic or endothermic.
- Perform calculations involving change in temperature, specific heat capacity, and heat.
- Use scientific reasoning skills (such as observing, measuring, inferring, and predicting) to problem-solve a solution for a simulated real-world situation.
- Relate ΔH and q.

Definitions

- **Calorimetry** – quantitative analysis of heat changes in a system
- **Combustion** – chemical reaction that occurs when a substance combines with oxygen; the reaction is often rapid and often produces heat and light
- **Dissolution** – the process of a solute mixing and dispersing within a solvent to form a solution
- **Endothermic reaction** – a reaction that absorbs energy in the form of heat
- **Enthalpy** – the sum of a system's internal energy; equal to heat in a chemical process if pressure is held constant and no work is done
- **Enthalpy of combustion** – heat released during combustion reaction
- **Enthalpy of reaction** – heat associated with a chemical reaction
- **Enthalpy of solution** – heat absorbed or released when a substance dissolves in a solvent
- **Exothermic reaction** – a reaction that releases energy in the form of heat
- **Heat** – a transfer of thermal energy; energy used to cause the temperature of an object to rise (has direction – flows from hot to cold)
- **Solute** – the component in least amount in a solution

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- **Solution** – a homogeneous mixture of a solute(s) and solvent
- **Solvent** – the major component of a solution
- **Specific heat capacity (C_s)**– the amount of heat needed to raise the temperature of 1 g of a substance by 1°C, units of J/g· °C
- **Temperature** – measures the average velocity of particles; a physical property that determines the direction of heat flow between two bodies in contact
- **Thermochemical equation** – a balanced reaction that includes the phases of each substance and the enthalpy of the reaction
- **Thermochemistry** – the study of heat or energy flow in chemical reactions

Introduction

You work for the research and development division (R&D) of "Warm-R-Us". Your team has been entrusted to design a heat pack for maintenance workers on the Alaskan pipeline. Your heat pack must be able to treat frostbite in a worker's hand (heat should be applied gradually, not directly; the treatment process would be addressed in a future phase in the development of this product). Today your team will focus on performing preliminary tests to develop a heat pack. That is why you will do each test only once. Once your team feels comfortable with the preliminary results, the next phases involve repeating tests, and meeting with the engineering department to create a prototype. You will not be participating in these next phases.

Heat and the Human Body

The human body works best within a very narrow temperature range. A temperature drop as little as 2°C in the body's core causes hypothermia symptoms such as mental difficulties and loss of physical coordination. Much more extreme temperature loss may be survived by the extremities but can lead to frostbite if the flesh freezes. Victims of hypothermia require immediate treatment, and in outdoor situations, the treatment is often warmth provided by portable heat sources, such as heat packs. Heat packs are available that produce warmth through various chemical reactions. Such heat packs are convenient because they only release heat when triggered. One common heat pack contains an internal pouch of water and a solid powder. Once the pouch of water is broken open, there is an exothermic reaction between the water and the powder. These heat packs have limitations. For example, they do not work well in extreme cold - the water will freeze.

In the coldest environments, heat packs are available that contain only the powder in a resealable waterproof sack. When heat is needed, the sack can be opened, and any aqueous solution poured inside. The sack is resealed, and the reaction produces heat. Any aqueous solution will work - melted snow, stream water, coffee, even urine. Some other heat packs do not require water – they are not based on solubility. For example, Thermacare® uses the heat produced by the oxidation of iron powder with oxygen.

As part of this lab, you will:

- measure the amount of heat involved in frostbite
- examine a possible heat-generating reaction for a heat pack
- use calorimetry to measure the heat generated by 1 gram of the reaction selected
- based on results of the heat generated by the reaction selected, calculate the amount needed to heat an average adult person's hand between 37°C and 40°C (a temperature above 40°C has the potential of burning the person treated)

Heat and Temperature

If an object (such as a pot of water) is positioned to absorb the heat given off during a chemical reaction, then the temperature of the object will change. Equation 1 allows us to determine the heat associated with the temperature change:

$$q = m \times C_s \times \Delta T \qquad \textit{Equation 1}$$

where: q = the amount of heat absorbed by the object, in J
m = the mass of the object being heated, in g
C_s = the specific heat capacity of the object, in $J/g \cdot °C$
ΔT = the change in temperature of the object, $T_f - T_i$

The specific heat capacity is different for different substances, as can be seen in Table 1.

Table 1. Specific Heat for Selected Substances

Substance	**Specific Heat Capacity** ($J/g \cdot °C$)
water	4.18
air	1.01
aluminum	0.897
granite	0.790

Exercise 1: How much heat is needed to raise the temperature of 5.00 g of granite from 25.0 °C to 40.0 °C?

$$q = m \times C_s \times \Delta T$$

$$= (5.00\ g)\left(0.790\ \frac{J}{g \cdot °C}\right)(40.0°C - 25.0\ °C)$$

$$= (5.00\ g)\left(0.790\ \frac{J}{g \cdot °C}\right)(15.0\ °C) = 59.\underline{2}5 = 59.3\ J$$

When two objects at different temperatures are placed in contact, heat flows from the substance at the higher temperature to the substance at the lower temperature until both materials reach the same final temperature. Based on the Law of Conservation of Energy, the amount of heat energy lost by the hot material equals the amount of heat gained by the cold material. Stated mathematically:

$$q_{material\ 1} = -q_{material\ 2} \qquad \textit{Equation 2}$$

The minus states that the heat change of material 2 is opposite in sign of material 1, not that material 2 is always negative. This relationship is usually used in calorimetry.

Calorimetry

Many experiments in thermochemistry involve a calorimeter. A calorimeter is simply a container that insulates a reaction from the surrounding environment. Usually, a calorimeter will have a water bath that changes temperature; up or down depending on whether the reaction is exothermic or endothermic, or whether an object is placed in the bath that is hotter or colder than the water. For many aqueous reactions, **the water bath is the solution itself**, as in the second part of this lab. Your calorimeter (see Figure 1) will consist of a thick Styrofoam cylinder closed on one end plus a Styrofoam lid (or one plastic lid plus two Styrofoam coffee cups, one nestled inside the other). Styrofoam is an excellent insulator, but with time, heat will slowly leak out of the cup. By plotting temperature of the solution versus time (see Figure 2), you will be able to extrapolate to determine the final temperature of the reaction more precisely. You will collect the data using a LabQuest Data Collector with a temperature probe. This system will collect the data for you and graph it.

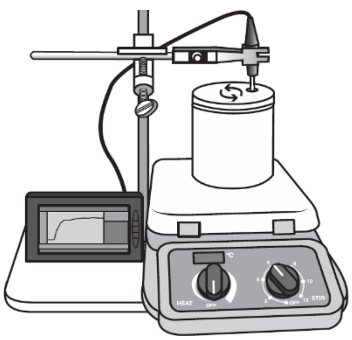

Figure 1. Calorimeter setup.

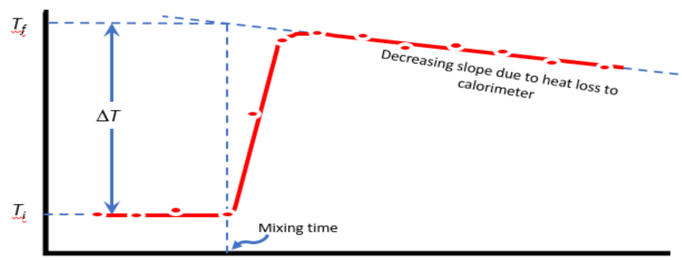

Figure 2. Temperature vs time for an exothermic reaction. (The intercept between the trendline of the decreasing slope and the vertical line at the time of mixing corresponds to the final temperature.) Image courtesy of Diego J. Diaz Lopez.

Exercise 2: A 55.0 g piece of metal was heated in boiling water to 99.8 °C and then dropped into a calorimeter containing 25.0 mL of water with an initial temperature of 23.4 °C. A graph similar to the one shown in Figure 2 was obtained. Using the graph, the final temperature of the metal and water was determined to be 26.1 °C. What is the specific heat of the metal? (Density of water is 1.00 g/mL.)

$$q_{H_2O} = m_{H_2O} \times C_{s\,H_2O} \times \Delta T_{H_2O} = \left[(25.0\,mL)\left(1.00\,\frac{g}{mL}\right)\right](4.18\,\frac{J}{g\cdot°C})(26.1\,°C - 23.4\,°C)$$

$$= (25.0\,g)\left(4.18\,\frac{J}{g\cdot°C}\right)(2.\underline{7}\,°C) = 2\underline{8}2.15\,J = 280\,J$$

$$q_{metal} = -q_{H_2O} = (-1)(2\underline{8}2.15\,J) = -2\underline{8}2.15 = -280\,J$$

To find the specific heat capacity of the metal use the calorimetry equation again:

$$q_{metal} = m_{metal} \times C_{s\,metal} \times \Delta T_{metal}$$

Solving for specific heat capacity, $C_{s\,metal}$, of the metal and substituting values:

$$C_{s\,metal} = \frac{-2\underline{8}2.15\,\text{J}}{(55.0\,g)(26.1°C - 99.8°C)} = \frac{-2\underline{8}2.15\,\text{J}}{(55.0\,g)(-73.\underline{7}°C)} = 0.06\underline{9}606$$

$$= 0.070\,J/g\cdot°C$$

Enthalpy of a Reaction

An important part of modern chemistry involves studying energy changes that occur during chemical reactions. These energy changes are of fundamental importance in understanding the "driving force" of a chemical reaction. The most common way energy is exchanged between a chemical system and the environment is by evolution or absorption of **heat, *q***. The change in heat energy accompanying a chemical reaction at constant pressure (q_p) is known as **enthalpy change, ΔH**. By convention, reactions in which **heat is absorbed** are labeled **endothermic** and have **positive values of ΔH** ($+q_p = +\Delta H$); reactions in which **heat is released** are labeled **exothermic** and have **negative values of ΔH** ($-q_p = -\Delta H$). Cold packs used in athletics are familiar to many sports enthusiasts. In order to derive coldness from the pack, a plastic packet of water is broken inside another packet containing a solid salt such as NH_4NO_3. In this case the **enthalpy of solution** is endothermic indicating that heat is absorbed as the salt dissolves, as can be seen in the thermochemical equation for NH_4NO_3 (see Equation 3). Thus, the enthalpy of solution is designated with a positive sign.

$$NH_4NO_3(\text{s}) \overset{H_2O}{\rightarrow} NH_4{}^+ + NO_3{}^-(\text{aq}) \qquad \Delta\text{H} = +25.70\text{ kJ} \qquad \textit{Equation 3}$$

The heat absorbed by this reaction, q_{rx}, can be measured using calorimetry. In this case, since the salt dissolves in the water, the heat absorbed or lost by the solution, q_{sln}:

$$q_{sln} = m_{sln} \times C_{s_{sln}} \times \Delta T_{sln} \qquad \textit{Equation 4}$$

where: $m_{sln} = mass_{salt} + mass_{water}$

$$C_{s_{sln}} = C_{s_{H_2O}}$$

$$\Delta T_{sln} = T_{f_{sln}} - T_{i_{water}}$$

$$q_{rx} = -q_{sln}$$

The amount of enthalpy (ΔH) or heat (q) absorbed or released by any reaction is calculated with Equation 5.

$$\Delta H = (mol\ of\ chemical\ x) \times \frac{\Delta H_{reaction}}{coefficient\ of\ chemical\ x} \qquad \textit{Equation 5}$$

Exercise 3: Determine the enthalpy absorbed by the dissolution of 125.0 g of solid ammonium nitrate in water.

This can be solved using Equation 5 and Equation 3:

$$?\,kJ = 125.0\ g\ NH_4NO_3 \times \frac{1\ mol\ NH_4NO_3}{80.052\ g\ NH_4NO_3} \times \frac{+25.70\ kJ}{1\ mol\ NH_4NO_3} = +\,40.1\underline{3}0165 kJ$$

$$= +40.13\ kJ$$

If we do not know the enthalpy of the reaction, but we have measured the heat involved with a certain mass, we can use this relationship to find another heat-to-mass or mass-to-heat relationship for the same reaction or process. This is presented in exercise 4.

Exercise 4: When 3.005 g of solid $MgSO_4$ were dissolved in 100.0 mL of water, the temperature of the water rose from 21.0 °C to 24.3 °C. This reaction is being considered by another team as a possible source for the heat pack. The heat needed to warm the surroundings is 2238 J. How many grams of $MgSO_4$ should be dissolved in 100.0 mL of water to generate 2238 J? Assume that the density of water is 1.00 g/mL.

Since the $MgSO_4$ will dissolve in the water, use Equation 4 to determine q_{sln}:

$$q_{sln} = (100.0\ g + 3.005\ g) \times \left(4.18 \frac{J}{g \cdot ^\circ C}\right) \times (24.3^\circ C - 21.0\ ^\circ C)$$

$$= (103.005\ g) \times \left(4.18 \frac{J}{g \cdot ^\circ C}\right) \times (3.3\ ^\circ C) = 1\underline{4}20.85\ J = 1.4 \times 10^3\ J$$

The heat of dissolution of 3.005 g of $MgSO_4$ in 100.0 mL of water is:

$$q_{MgSO_4} = -q_{sln} = -1\underline{4}20.85\ J$$

Therefore the heat per g of $MgSO_4$ would be:

$$q_{MgSO_4}/g = \frac{-1\underline{4}20.85\ J}{3.005 g} = -4\underline{7}2.828\ J/g$$

Now use this relationship to find the mass associated with −2238 J (generates, so it is an exothermic process).

$$?\ g_{MgSO_4} = -2238\ J \times \frac{1\ g}{-4\underline{7}2.828\ J} = 4.\underline{7}33 = 4.7\ g$$

Techniques

Technique

- Technique 2: Using a balance
- Technique 4: Using a graduated cylinder
- Technique 18: Measuring temperature
- Technique 20: Using the LabQuest data collector with temperature probe

List of Chemicals

- Vienna sausage
- NaCl
- KCl
- $CaCl_2$

List of Equipment and Glassware

- one LabQuest Data Collector with a thermal probe
- one 250-mL beaker
- one 50-mL beaker
- one 18 mm × 150 mm test tube
- one test tube rack
- one crucible tongs
- one small beaker or watch glass
- one calorimeter with its lid
- one magnetic stirrer
- one magnetic bar
- one 100-mL graduated cylinder or larger
- six 13 mm × 100 mm test tubes
- one ruler that measures cm
- one thermometer
- stand and utility clamp

Experimental Procedure

This experiment will require most of the time allocated to the lab period. If you are not well prepared and do not use your time wisely, you will not be able to complete this experiment. Points will be deducted for areas not completed. You will need to deal with deadlines and crunch times when you work in private industry. Preparation is key, as well as time management and proper coordination with your team member(s).

Part A Estimation of the Heat Capacity of a Human Hand

Obviously, heat must be taken from a person's hand to cool it down, and heat must be added to warm it up again. However, how much heat is governed by the hand's **specific heat capacity**. To know how much heat is needed to warm a hand, you first need to estimate the specific heat capacity of a hand. Your research team has noticed the eerie similarity between a Vienna sausage and a human hand. Once you determine the heat capacity of a Vienna sausage, you will use it to estimate the heat capacity of an average size adult human hand.

Record the data of this section in Data Table 1.

1. One team member should collect a LabQuest Data Collector with the thermal probe and instructions sheet and proceed to set it up following the instructions sheet. **Set the "Interval" to 5 s/sample and the "Duration" 1000 s. Re-enter these settings before each new run.** (Ignore the rate; the LabQuest automatically adjusts it when the interval is entered.)

Technique 20

2. Meanwhile, the other team member should:
   a. Collect a 250-mL beaker, an 18 mm X 150 mm test tube, a test tube rack, crucible tongs, and one Vienna sausage (use the tongs to place it in a small beaker to transport it to your area - don't squish it).
   b. Measure the mass of the Vienna sausage (do not place it directly on the balance). Record this value in Data Table 1.

Technique 2

c. Create an ice slush in the 250-mL beaker: fill the beaker approximately $^2/_3$ with ice and add just enough water to produce a slush (see Fig. 3). The goal **IS NOT** to make ice water, but to make packed ice with water between the pieces of ice.

d. Add tap water to the test tube until it is approximately ¾ full and leave it in the test tube rack (it will be used later to return the probe to room temperature before placing it in the calorimeter).

3. Insert the temperature probe through the Vienna sausage, lengthwise (see Fig. 4). Submerge the Vienna sausage and probe in the ice slush. If the ice slush melts into ice water during the experiment, remove some water and refill with ice to recreate the slush. Leave it there until the sausage is at constant temperature (the LabQuest is displaying the sausage's temperature). Monitor the time – you want it to be in the ice slush for at least 12 minutes to achieve a temperature near that of the ice bath. Meanwhile, continue with the next steps.
4. Obtain a calorimeter with its lid and a magnetic bar. (If using two coffee cups, place the cups in a 250-mL beaker for stability).
5. Weigh the calorimeter with its lid.
6. Using the graduated cylinder, measure 100.0 mL of deionized water. Pour it into the calorimeter and reweigh the calorimeter with its lid. Calculate the mass of the water.

Technique 4

7. Setup the equipment as shown in Figure 1, minus the temperature probe (do not remove it from the sausage yet):
   a. Place the magnetic bar in the calorimeter.
   b. Place the magnetic stirrer on the stand (if using a magnetic stirrer/hot plate unit, make sure the heating feature is off).
   c. Place the calorimeter on the magnetic stirrer and turn the stirrer on so that the magnetic bar is gently stirring the water without splattering. Place the calorimeter lid on the calorimeter.
   d. Place a utility clamp on the stand and position it is slightly above the **outer** hole of the lid.
8. Has it been at least 12 minutes since you placed the sausage in the ice slush? If so, record the temperature of the sausage, which is being measured by the LabQuest Data Collector, in Data Table 1 item 10 - T_i initial temperature of sausage.
9. Remove the temperature probe from the sausage (leave sausage in the ice bath), wipe it with a paper towel and insert it into the test tube containing water to restore it to room temperature (wait until its temperature stops increasing as displayed on the LabQuest).
10. Remove the temperature probe from the test tube and dry it with a paper towel. Suspend it from the clamp and insert it through the outer hole on the lid. Adjust the clamp so that the probe is submerged as low as possible in the water but high enough above the lid so that you can open the lid by rotating it without lifting the probe (see Fig. 5).

<u>Golden Lab Rule</u>: Be careful not to poke a hole in the calorimeter with the probe.


Figure 3. Ice slush.

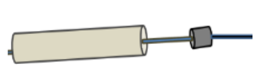
Figure 4. Sausage & probe.

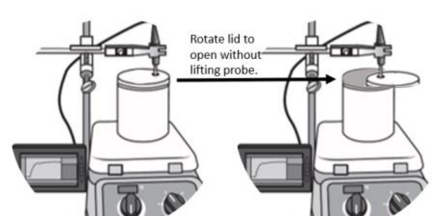

Figure 5. Rotate lid to open & close calorimeter.

11. Wait until the temperature probe equilibrates with the temperature of the water. Record this temperature in Data 1 item 5 - T_i, initial temperature of water.
12. Press “play” on the LabQuest Data Collector to begin data collection. After obtaining three or four readings (after 15-20 seconds) at the same temperature, rotate the lid and quickly transfer the sausage from the ice slush into the calorimeter. To transfer, pick up the Vienna sausage with crucible tongs, and quickly shake any ice pieces and excess water from the sausage before putting it into the calorimeter. Be careful not to splash any water out when you put the sausage in the calorimeter. Replace the lid. (While the data is being collected, one of the team members should start collecting the chemicals stated in steps B1 and B2.)

Note 1: To adjust graph size during the run, select “Graph” from the top tool bar of the LabQuest Data Collector (see Figure 6), then select “Auto Scale Once”.

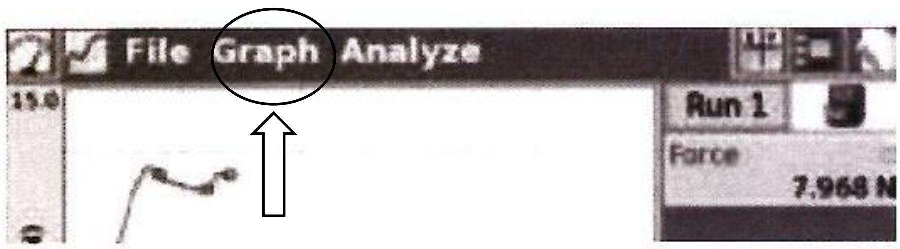

Figure 6. Adjusting graph display on LabQuest

Note 2: If the data collection stops too soon, hit play again and select “Append”. The graph may have a little gap, but since you want the general trend of the slope it will be okay.

13. Stop data collection once the temperature starts increasing at a steady pace or reaches a plateau. Save the run.
14. Dispose of the Vienna sausage in the regular trash can. Pour the water in the calorimeter down the drain and invert the calorimeter over a paper towel. Meanwhile, the other team member should print the graph (print one copy for each team member) following the instructions sheet located next to the laptops.
15. Using a pencil, draw two lines on the graph similar to the ones shown in Figure 2:
    - draw a vertical line parallel to the y-axis at the mixing point
    - draw a trendline for the data collected in the region of increasing/decreasing slope due to heat gain/loss of the water; extend it until it intersects the mixing line

    The “y” value of this intersection point corresponds to T_f for the sausage and for the water.
16. Complete Data Table 1, including calculations.
17. The average size of an adult person’s hand is approximately equivalent to 16 Vienna sausages. Based on the mass of the Vienna sausage you weighed, estimate the mass of an average adult person’s hand. Then calculate how much heat would be required to raise the temperature of an average adult person’s hand from 15.0 °C to 37.0 °C. Record these values in Data Table 2.

Part B Selecting a Material for the Heat Pack

There are three options for salts to use in the heat pack: NaCl, KCl, and $CaCl_2$. In this part of the procedure, you will do a quick screening to determine which produces heat when it dissolves in water. Record this data in Data Table 3**.**

The dissolution reaction for the first salt is shown in Equation 6.

$$NaCl(s) \overset{H_2O}{\rightarrow} Na^+(aq) + Cl^-(aq) \qquad \textit{Equation 6}$$

1. Obtain six 13 mm × 100 mm test tubes. Add approximately 2 cm of deionized water to three of these test tubes (rulers are available in the lab).
2. Add approximately 1 cm of NaCl into the 4th test tube, approximately 1 cm of KCl into the 5th test tube, and approximately 1 cm of $CaCl_2$ into the 6th test tube (label each test tube).
3. Using a thermometer, measure and record the temperature of the water in one of the test tubes.
4. Remove the thermometer and pour this water into the test tube containing the NaCl. Place the thermometer inside of this mixture and stir gently with the thermometer. Be extra careful to prevent breaking the thermometer.

Technique 18

5. Record the temperature of this solution after 30 seconds.
6. Rinse the thermometer with water, wipe it dry and place it in another test tube containing water.

Golden Lab Rule: *Collect rinsed chemicals in waste beaker.*

7. Repeat Steps 3-6, but use KCl in place of NaCl.
8. Repeat Steps 3-6, but use $CaCl_2$ in place of NaCl.
9. Below table 3, write a note concluding which salt would work best to fashion a heat pack, and why. Show conclusion to your professor for approval/signature before proceeding.

Part C Measure Enthalpy per Gram Produced by Dissolution of Selected Salt

Record the data collected from this part in Data Table 4 (create this table).

Technique 4

1. Using a paper towel, dry the calorimeter and lid previously used.
2. Add 75.0 mL of deionized water to the calorimeter.
3. Measure the mass of the calorimeter, lid and water. Calculate the mass of the water.
4. Add a magnetic bar into the calorimeter.
5. Place the calorimeter on the magnetic stirrer and place the temperature probe through the outer hole on the lid. Turn on the magnetic stirrer. Again, make sure the water does not splatter, the magnetic bar is not hitting the probe, and the probe is submerged in the water as much as possible while at the same time allowing enough space so that the probe does not touch the bottom of the calorimeter and the lid can rotate.
6. Weigh and record the mass of a boat.
7. Add approximately 1.0 g of the selected salt into the boat. Record the mass of the boat and salt.
8. After re-entering the "Interval" and the "Duration" stated in Part A on the LabQuest Data Collector, press play to begin data collection. After obtaining three or four readings, rotate the lid, and quickly transfer the measured salt into the calorimeter. If some of the salt adhered to the boat, reweigh it. Use this value as the initial mass of the boat so that you can calculate the exact mass of salt transferred into the calorimeter.
9. Stop data collection once the temperature starts decreasing or increasing at a steady pace. Save the file.

10. Print the graph (one for every team member), add a title, and draw the two lines as done previously. Record the initial temperature of the water, T_i, and the final temperature of the solution, T_f.
11. Calculate ΔT_{sln}, the heat change of the solution and the enthalpy of the reaction per gram of salt. In your calculations, you can assume the following:
    - the mass of the solution is the mass of the salt plus the mass of the water
    - the specific heat of the solution is the same as that of water, 4.18 J/ g·°C

Part D Completing the Heat Pack Design

As stated previously, your goal is to design a heat pack for maintenance workers on the Alaskan pipeline. Your heat pack must be able to treat frostbite in a worker's hand without burning them.

Calculate the mass of the salt selected that is expected to deliver the amount of heat needed to treat an average adult person's hand within a safe temperature range (see Table 2). Include this value in Table 4 and show your calculations below Table 4.

Unfortunately, you have been reassigned to a different project next week, so you will not be able to participate in the next phase of this project, which consists of performing tests to determine if the calculated mass actually heats the sausages to the desired temperature range.

Clean up/Disposal

- Dispose of the Vienna sausage in the regular trash can.
- Pour the salt solution (from the test tubes and calorimeter) into the Inorganic Waste container.
- Wash and dry the outside of all glassware and return to original location.
- Wipe the temperature probe clean.
- Delete your graphs from the LabQuest. Turn it off and remove the temperature probe. Store it as originally found in its original location. Return LabQuest directions.

Technique 11

References

1. Lesher, E. St. Joseph's College of Maine, Standish, ME. Unpublished work, 2016.
2. Vannatta, M. W.; Richards-Babb, M.; Sweeney, R. J. Thermochemistry to the Rescue: A Novel, Calorimetry Experiment for General Chemistry. *J. Chem. Educ.* 2010, *87*, 1222-1224.

Pre-lab

1. Read the procedure several times. You need to be extra prepared to ensure you finish this experiment in its entirety. Write a statement to this fact. If you do not feel prepared, write questions and make sure you get them clarified before coming to lab (email questions to your professor – make sure you give them enough time to reply).
2. Design Data Table 4.
3. Nitroglycerin, $C_3H_5N_3O_9$, is an unstable compound that decomposes rapidly upon ignition or impact. Below is the thermochemical equation for nitroglycerin:

   $$4\ C_3H_5N_3O_9(l) \rightarrow 12\ CO_2(g) + 10\ H_2O(g) + 6\ N_2(g) + 13\ O_2(g)\ \Delta H_{rx} = -5678\ kJ$$

   What mass of nitroglycerin is needed to generate $-7285\ kJ$?
4. Propane, C_3H_8, is used by many campers to cook on the trail. The thermochemical equation for the combustion of propane is shown below.

   $$C_3H_8(g) + 5\ O_2(g) \rightarrow 3CO_2(g) + 4\ H_2O(g)\quad \Delta H_{rx} = -2043\ kJ$$

   If 5.00 g of propane is burned and all the heat from this combustion is absorbed by 400.00 g of water at an initial temperature of 20.0 °C (ignore the pot holding the water), what is the final temperature of the water?
5. Write the dissolution reactions of KCl(s) and $CaCl_2$(s) in water.

Post-lab

Your stapled report should include of all of the following in this order:

- Data Tables 1-4 with calculations.
  - Don't forget to add titles to tables 3 and 4.
- Two graphs with titles, trend lines and T_f identified on each graph.

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Experiment 8: Calorimetry
Experimental Data and Calculations

Name: ____ **Date:** _______________________

Lab Partner: ____ **Section:** _____________

Data Table 1. Determination of the Specific Heat Capacity of One Vienna Sausage

1) Mass of the Vienna sausage	
2) Mass of calorimeter and lid	
3) Mass of calorimeter and lid + water	
4) Mass of the water	
5) Ti, initial temperature of water	
6) Tf, final temperature of water	
7) ΔT, change in temp of the water	
8) Heat change of water	
9) Heat change of sausage	
10) Ti, initial temperature of sausage	
11) Tf, final temperature of sausage	
12) ΔT, change in temp of the sausage	
13) Specific heat, Cs, of one sausage	

Calculations:

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Data Table 2. Estimation of the Heat Needed to Warm an Average Size Adult Person's Hand

1) Estimated mass of 16 Vienna sausages	
2) Heat needed to warm 16 Vienna sausages from 15.0 °C to 37.0 °C	

Calculations:

Data Table 3. ______________________________

	NaCl	KCl	$CaCl_2$
1) temperature water			
2) temperature of mixture at 30 s			
3) ΔT			
4) visible observations of mixture			
5) type of reaction (i. e. endothermic or exothermic)			

Conclusion:

Professor's approval signature for salt selection ______________________

Name: ____

Table _____. ____

(**Read over Part C**. Develop your own Table before coming to Lab. Note: you do not need to use all the columns and rows in the table below. Extra provided to not limit your creativity.)

$\Delta H_{rx}/mass_{salt}$ (J/g)		
Mass of salt needed to warm an adult person's average hand (Table 2)		

Calculations:

Report: The laboratory report should include Tables 1-4 (add titles to tables 3 and 4) with calculations, and the two graphs with titles, trend lines and T_f identified.