DNAZone Classroom Kit Teacher Guide

Kit title	Where Does the Heat Go? Calorimetry and Thermodynamics
Appropriate grade level	Upper high school, AP Chemistry
Abstract	The concept of calorimetry is part of thermodynamics, focusing on problems relating to energy and heat. These topics are not only crucial parts of standardized exams, but are also largely present in everyday life. Learning these concepts through hands-on experiments enhances a student's understanding while also sparking their curiosity and interest. The teaching plan suggested in this classroom kit follows the PPP model, which stands for presentation, practice and production. The following set of activities emphasizes how hand warmers and instant cold packs utilize endothermic and exothermic reactions to produce heat or absorb heat. By doing so, the students will be able to determine the amount of heat involved in illustrative chemical reactions and then evaluate mathematical formulas to calculate the efficiency of specific chemical and mechanical systems.
Activity time	Approximately one hour: • Two 25-minute activities • One 10-minute demonstration
PA Department of Education Standards	**Process Standards** **3.4.12 B.** Apply and analyze energy sources and conversions and their relationship to heat and temperature. **Content Standards** **3.1.12 B.** Apply concepts of models as a method to predict and understand science and technology **3.2.12 C.** Apply the elements of scientific inquiry to solve multi-step problems **3.2.12 D.** Analyze and use the technological design process to solve problems
Next Generation Science Standards	**HS-PS1** Matter and Its Interactions • HS-PS1-5 Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. *[Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.]* [*Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature*.] • HS-PS1-6 Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of

	products at equilibrium. *[Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.]* [*Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.*] **HS-PS3** Energy • HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. *[Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.]* [*Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.*] • HS-PS3-4 Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). *[Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.]* [*Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.*]
References	Elephant Toothpaste. http://www.youtube.com/watch?v=tnB-uU3w6g8 (accessed June 29, 2012). Science Buddies Staff. "Cold Pack Chemistry: Where Does the Heat Go?" *Science Buddies*. Science Buddies, 23 Oct. 2014. Web. 7 Nov. 2014 <http://www.sciencebuddies.org/science-fair-projects/project_ideas/Chem_p081.shtml>
Kit creation date	June 29, 2012

"Where Does the Heat Go? Calorimetry and Thermodynamics" Overview

Educational Objectives

1. Students will be able to determine the heat involved in chemical reactions
2. Students will be able to identify endothermic and exothermic reactions
3. Students will be able to evaluate the mathematical formulas that calculate the efficiency of specific chemical and mechanical systems
4. Students will be able to induce problem solving skills for quantitative analysis

Teacher Preparation Time

- Teachers should allow enough time to review the background information included in this teacher guide and the accompanying PowerPoint presentation.
- Elephant toothpaste demonstration: < 5 minutes (to get the reagents and workbench ready)
- Cold packet activity: none
- Heat packet activity: boil water

Required Student Knowledge

Chemical reactions (formulas for basic chemical compounds)

Part I: Elephant Toothpaste – An introduction to catalytic chemical reaction and thermodynamics

Demonstration Time: Approximately 10 minutes

Objectives: To serve as an introduction to the thermodynamics unit and engage students

Background Information:
Elephant toothpaste is a common and exciting chemistry demonstration. It involves an exothermic reaction in which hydrogen peroxide is converted to water and oxygen. The dishwashing soap that is added to the graduated cylinder captures the oxygen produced as bubbles and streams from the graduated cylinder as heat is released. Potassium iodide acts as a catalyst and initiates the reaction. Food coloring is added to make the foam more aesthetically pleasing.

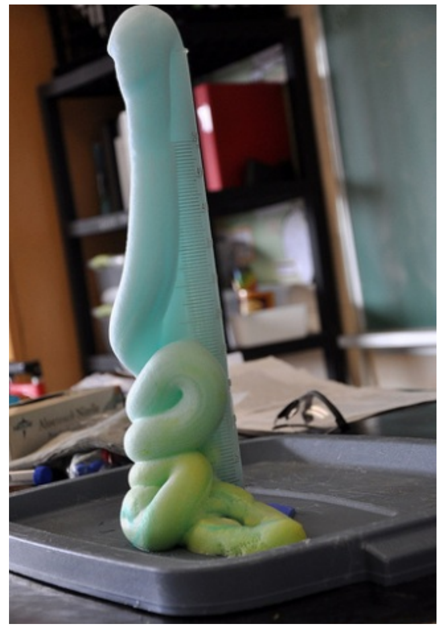


Figure 1:
Elephant toothpaste demonstration

The overall equation is the following:

$$H_2O_2\,(aq) + \cancel{I^-}\,(aq) \text{ --> } \cancel{OI^-}\,(aq) + H_2O(l)$$

$$\underline{H_2O_2\,(aq) + \cancel{OI^-}\,(aq) \text{ --> } \cancel{I^-}\,(aq) + H_2O(l) + O_2(g)}$$

$$\mathbf{2\ H_2O_2\,(aq) \text{ --> } 2\ H_2O(l) + O_2(g)}$$

Fun Fact:
Hydrogen peroxide is used to fuel rockets, motorbikes, and airplanes!

Procedure:

1. First hand out the pre-demonstration quiz (page 4) and have the students fill it out
2. Lay down newspapers or paper towels on the workbench to make cleanup easier
3. Add 20mL 30% hydrogen peroxide to the 500 mL graduated cylinder
4. Add approximately 5mL of dishwashing soap (preferably one without color) to the same graduated cylinder
5. Have the students decide which color they want to use
6. Add 5 drops of the desired food coloring to the same graduated cylinder
7. Have a volunteer come up and add 5g of potassium iodide to the same graduated cylinder and stand back
8. The reaction will produce heat and will foam up vigorously

Reference: http://www.youtube.com/watch?v=tnB-uU3w6g8

Name______________________________
Date_______________________________

Elephant Toothpaste Pre-Demonstration Quiz

1. What is characteristic of any compound that contains peroxide?
   a. It contains oxygen-oxygen bond
   b. It contains a hydrogen-oxygen bond
   c. It contains single oxygen
   d. It contains a hydrogen-hydrogen bond
   e. It is exceptionally stable

2. Hydrogen peroxide decomposes into
   a. Oxygen gas and hydrogen gas
   b. Oxygen gas and water
   c. Hydrogen gas and water
   d. Water only
   e. Three different products

3. A kind of chemical reaction in which one substance breaks apart to form two or more substances is known as a
   a. Combination reaction
   b. Single replacement reaction
   c. Double replacement reaction
   d. Decomposition reaction
   e. Splitting reaction

4. Decomposition in a sense of chemical reaction means
   a. Combining
   b. Smelling
   c. Breaking apart
   d. Turning sour
   e. Digesting

5. A gas
   a. Occupies more volume than the liquid from which it is formed
   b. Is lighter than the same amount of solid
   c. Can exist only at temperature above room temperature
   d. Wants to fill the entire room if the bottle it is in is opened
   e. Can foam if the detergent is present

Part II: Calorimetry of Instant Cold Packs

Activity Time: Approximately 25 minutes

Objectives:

- To be able to quantitatively analyze the amount of heat transferred through the instant cold packs
- To be able to evaluate the specific heat by the mathematical formula
- To be able to better understand how chemical reactions release or absorb heat

Background Information:

Instant ice packs are often used in sport injuries and other common injuries that happen around the home. They are convenient substitutes to bags of ice or frozen peas when it is necessary to calm swelling. An instant ice packs works simply by squeezing the bag; after a couple minutes the bag will feel cool to the touch.

The mechanism behind the instant ice pack is simple. The pack contains two pouches: and outer pouch filled with ammonium nitrate and a smaller, inner pouch filled with water. When someone squeezes the ice pack, they break the inner pouch filled with water. The water combines with the ammonium nitrate and the ammonium nitrate begins to dissolve. When the ammonium nitrate dissolves, heat is absorbed and an endothermic reaction occurs.

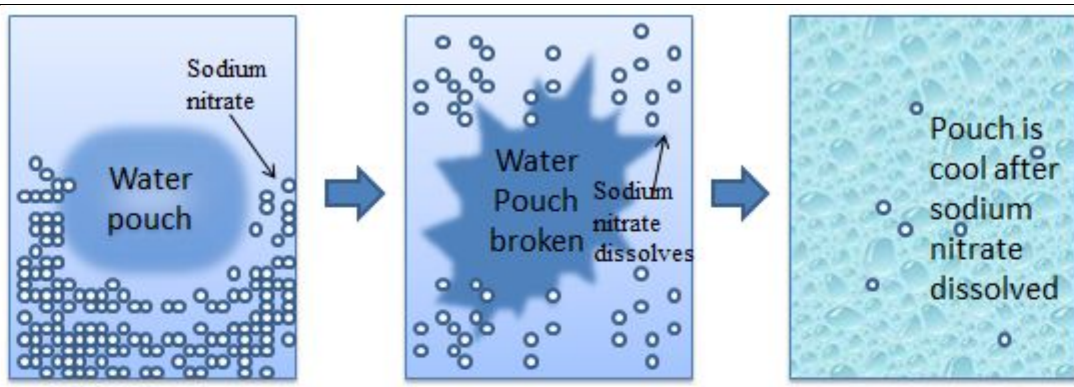


Figure 2. How an instant ice packs works (step 1 → step 2 → step 3)

Ammonium nitrate is a salt and contains electrically charged particles called ions. In step 1 (shown in figure 2), the solid ammonium nitrate crystals break into ions. It takes a lot of energy to break an ionic bond, so heat is absorbed from the environment in order for this reaction to occur. In step 2 (shown in figure 2), the water molecules are attracted to these ions and therefore attach themselves to the ions. Heat then flows to the surroundings as seen in equation 2 and 3.

NH_4NO_3+ Heat → NH_4^+ + $NO3^-$ **eq. 2**

NH_4^+ + NO_3^- + H_2O → $NH4^+(H_2O)x$ + $NO_3^-(H_2O)x$ + Heat **eq. 3**

Several water molecules bind to each ion, as indicated by x. Although step 2 (shown in figure 2) releases heat, step 1 (shown in figure 2) requires much more heat and energy. Therefore, the overall reaction absorbs heat from its surroundings, leaving less thermal energy.

Other compounds that get cold when dissolved in water include potassium nitrate and potassium chloride.

How Much Heat was Lost in the Instant Ice Pack?

You're at a football game and the game is tied. You and the whole crowd are cheering for the home team when the quarterback throws his shoulder. The coach immediately pulls him out and grabs an instant ice pack, squeezes the ice pack, and applies it to the quarterback's shoulder for a couple minutes. Soon after, the quarterback is ready to go back on the field!

In this experiment, you will be experimenting with the chemistry behind instant ice packs. You will be quantitatively analyzing exactly how much heat is lost in this endothermic reaction.

Procedure

For this activity, split your class into groups of 2-3 students. Designate 1/5 of the class to use 10/20/30/40/50g of ammonium nitrate.

1. *Collect the ammonium nitrate from the instant cold pack, as follows:
   a. Put on your safety goggles and latex gloves
   b. Shake the instant cold pack gently to move the water bag and crystals to the bottom
   c. Cut the top of the bag off
   d. Pour the ammonium nitrate crystals into the plastic bowl/beaker
   e. Dispose of the water bag

   * ***Teacher:*** *this can be prepared ahead of time*

Figure 3. Ammonium nitrate from an instant cold pack

2. Cover the work surface with newspaper.

3. Add 100 mL of distilled water to one Styrofoam cup.

4. Place one of the wax paper squares on the scale

   a. Zero the scale.
   b. Use a plastic spoon to add the designated amount of ammonium nitrate on the square/weigh boat (10., 20., 30., 40. or 50.g)
   c. Record the weight

Note: You may need to divide the ammonium nitrate onto two or more pieces of wax paper/weigh boats if it will not all fit on one piece.

5. Record the starting temperature of the water in cup #1 in a data table in your lab notebook

    a. Point the digital thermometer at the water's surface and push the "on" button to get the temperature

5. Add the weighed ammonium nitrate to the water in cup #1; immediately start a timer

6. Stir the contents with a plastic spoon

    a. Record the temperature every 5-10 seconds in the first 30 seconds after the addition, then every 15 seconds until the temperature stabilizes
    b. Students should work in groups of 2+. One student writes the times and temperatures down and one takes the readings and stirs the solution.
    c. Stir the contents of the cup gently between each reading
    d. Remove the spoon when taking the temperature, as it may cause an error in the reading
    e. Stop taking readings when the temperature stops decreasing

7. Dispose of the ammonium nitrate solution down the sink. Note: Be sure to record the starting temperature, the intermediate temperatures, and the final temperature for each sample.

8. Repeat steps 2–8 two more times to get a total of three trials, with new and clean materials and equipment, adding the same designated amount of ammonium nitrate. This ensures that your results are accurate and repeatable. Create a new data table for each trial. You can reuse the spoons for the new trials, after rinsing them thoroughly with water.

9. Save any leftover ammonium nitrate from the cold packs for the other groups in the class.

10. Dissolve any leftover ammonium nitrate in water and dispose of it in a sink

Analyzing Your Results

1. Look at your data tables. Subtract the ending temperature from the beginning temperature for each cup. Is the change in temperature consistent in the three trials?
2. Graph the data, with time elapsed on the x-axis and the temperature on the y-axis.
3. How does the temperature change soon after the addition? How does the temperature change after the solids are dissolved? Is there a difference, and if so, why?
4. Compare the average change in temperature you measured with the other group in the class that used the same designated amount of ammonium nitrate. Are the results consistent?
5. Compile all data from the class, and add the mass of ammonium nitrate dissolved to the data table.
6. Graph the data, with the grams of ammonium nitrate on the x-axis and the temperature difference on the y-axis.
7. How does the final temperature change as more ammonium nitrate is added?
8. Using Equation 1 from the Introduction, calculate the heat energy, q, in joules, that each sample lost.
    a. Use the heat capacity value from Equation 2 for "c."
    b. Use the total mass (water plus ammonium nitrate) for "m": 110 g for cup #1, 120 g for cup #2, etc.
    c. Use the temperature change from the table for T1 - T2.
9. Graph the results, with the amount of ammonium nitrate in grams on the x-axis and the heat energy (q) on the y-axis.

Note: Students with access to graphing calculators and/or a computer (e.g. Microsoft Excel) can import the data into such devices and generate plots. Various regressions could be used to fit the data plot, such as linear, quadratic, exponential and logarithmic.

Part III: Calorimetry of Instant Hand Warmers

Activity Time: Approximately 25 minutes

Objectives:

- To be able to better understand how chemical reactions release or absorb heat
- To be able to qualitatively observe the crystal formation of sodium acetate and its application in hand warmers.

Background Information:

The most commonly used hot pack is shaken vigorously to release heat and keep the hands warm. The pouch contains a mixture of powdered iron, sodium chloride, activated charcoal, and sawdust, all dampened with water. In the pouch, the iron is oxidized and produces iron oxide (or rust), which forms an ionic bond and releases heat (eq.5). As you may notice in our everyday lives, rain or even salt can speed up a rusting process. Using this same idea, the mixture inside the hot pack is dampened with water in order to speed up the oxidation process.

Figure 3. Instant hand warmers that use iron

$$4\,Fe + 3\,O_2 \rightarrow 2Fe_2O_3 + \text{Heat} \qquad \textbf{eq. 7}$$

Another kind of warmer, however, involves a phase transition rather than a chemical reaction. This hot pack looks like a small air mattress filled with a clear liquid that has the viscosity of honey. In the corner of this pouch is a small metal disk. When this metal disk is flipped back and forth, it releases a triggering crystal. Heat is then released and the liquid slowly crystallizes the liquid.

Water has three different phases that it can exist in; solid (below 0^oC), liquid (room temperature), and gas phase (above 100^oC). Under certain conditions water can exist in a liquid phase under 0 degrees Celsius. A chemical that remains in a liquid phase at a temperature below its freezing point is called a supercooled liquid. An example of a supercooled liquid is this hot pack, which contains sodium acetate. Sodium acetate has a freezing point of 54^oC (130^o F). As the seed crystal is triggered from the metal disk, more crystals form around that seed until the whole heat pack is covered and the phase transition is complete from liquid to solid. As more bonds are formed, it releases heat. A valuable trait of this phase transition is that this cannot overheat. The temperature will rise to the freezing point and stay there. Also, this heat pack is reusable by boiling it in hot water for 15 minutes, which will melt the crystals and will turn it back into liquid phase until another seed crystal is triggered by bending the metal disk.

Le Chatelier's Principle:

Equilibrium is an important concept in thermodynamics. Suppose there is such a reaction where:

$$A + B \rightleftharpoons C + D \qquad \textbf{Eq. 4}$$

The reaction would be at equilibrium when the concentrations of the reagents (A and B) and products (C and D) are at optimum and show no tendency to change. The system, however, is subjected to change in concentration of the reagents/products (e.g. adding in more A), temperature (e.g. increasing the temperature of the surroundings), volume and pressure.

The Le Chatelier's Principle dictates that a disturbance to the chemical equilibrium will induce an opposing reaction to restore the status quo, i.e. driving the reaction to the opposite direction.

Example 1: if an excess amount of A is added in equation 4, the reaction is not at equilibrium, and it is favorable to consume A (since A is in excess), and produce C and D until equilibrium is reached. Therefore, the addition of A would result in the production of more C and D.

Example 2: Imagine C is CO_2 (g) and evaporates upon production. Whenever C and D are produced and the equilibrium is reached, C evaporates out of the system, and the system is not at equilibrium again! Therefore, the reaction continues to consume A and B in hopes of reaching equilibrium until either reagent is completely used up; meanwhile, C keeps disappearing. This is analogous to a leaking water bottle – one keeps adding water to it but eventually the water will all be gone.

Energy in the form of heat can also be considered as a reagent or a product in the reaction. If heat is produced, the reaction is exothermic (equation 5); if heat is consumed, the reaction is endothermic (equation 6). The Le Chatelier's Principle is also applicable in adjusting heat to restore the equilibrium.

$$A + B \rightleftharpoons C + \text{Energy} \qquad \text{Eq. 5}$$

$$A + \text{Energy} \rightleftharpoons C + D \qquad \text{Eq. 6}$$

Example 3: Imagine one is boiling water (equation 7).

$$H_2O\ (l) + \text{heat} \rightleftharpoons H_2O\ (g) \qquad \text{Eq. 7}$$

If one increases the heat (e.g. by raising the temperature on a heating mantle or cranking up the stove), more water boils off. If one removes the heat, water will slowly stop boiling off, and eventually the reaction will cease.

In this activity, students will predict the difference in the rate of heat production at different starting temperature using the Le Chatelier's Principle, and compare their hypotheses with experimental results.

Instant Hot Pack Activity: Observing Crystallization Growth

Important Notes Before You Begin:

- In this activity, you will observe how the starting temperature affects the rate of crystal growth, the size of the crystals, and the temperature in the hand warmer after activation.
- The procedure calls for varying the starting temperature of the hand warmer. The starting temperatures will be approximately 0°C, 20°C, and 40°C. To get the hand warmers to these temperatures, you will place the hand warmers in various water baths. The water bath at 0°C will be just ice water. The hot water bath will be made by adding hot water to room temperature water until the proper temperature is obtained.
- The class will be divided into three groups: a third of the class will experiment on the heat packet at room temperature, a third at a low starting temperature, and a third at a high starting temperature.

Procedures

For this activity, split your class into groups of 2-3 students. Designate 1/3 of the class to use an ice bath/room temperature water bath/warm water bath in the experiment.

#1: Experiments on heat packet at room temperature

1. Add room-temperature tap water to one Styrofoam cup so that the water level will cover a hand warmer, but do not place a hand warmer in there yet. Record the temperature of the tap water.
2. Place a hand warmer in the water bath at room temperature.
3. Allow a few minutes for the hand warmer to come to the same temperature as the water in the cooler.

Note: In the following steps, be ready with a timer and the infrared thermometer to observe and record the changes that occur after crystallization is initiated. Have a helper assist you in taking readings and writing the data.

4. Remove the hand warmer from the 20° water bath.
5. Place the hand warmer in a Styrofoam cup.
   - This insulates the hand warmer so that heat lost to the surface is minimized.
6. Record the starting temperature and the time in your lab notebook.
7. Snap the metal disk in the hand warmer and start the timer. Start the timer at the same time as you snap the disk.
8. Record the temperature of the hand warmer every minute for 15 minutes.
   - Feel free to change the time or duration of the measurements if you choose, but be sure to use the same time/duration for each trial. For example, take the temperature every 10 seconds for the first minute and every minute for 15 minutes thereafter.

9. Remove the heat packet from the Styrofoam cup upon completion.

Crystal growth observations:

1. Place a hand warmer in the water bath at room temperature.

2. Allow a few minutes for the hand warmer to come to the same temperature as the water in the cooler.

3. Remove the hand warmer from the 20° water bath.

4. Place heat packet on a flat surface (*be sure to have paper towels or newspaper underneath it to avoid burning the surface)

5. Snap the metal disk in the hand warmer and start the timer. Start the timer at the same time as you snap the disk.

6. Time how long it takes for the entire hand warmer to crystallize.

- Watch the hand warmer carefully as the crystals form.
- Use your judgment about when the entire contents of the hand warmer have crystallized.
- Write down your criteria for determining that the entire contents of the hand warmer have crystallized.

7. Observe the crystals that are formed. Write all observations in your lab notebook.

- Record their shape.
- Record the maximum length of the crystals.
- It will be difficult to obtain precise measurements of the crystals' length in the hand warmer since they break easily and grow into each other. Just do your best to estimate.
- As an option, photograph or film the hand warmer during crystallization and analyze the images later. Include a ruler in the pictures so you know the scale.

#2: Experiments on heat packet at a low starting temperature

1. Add room-temperature tap water and ice to one Styrofoam cup so that the water level will cover a hand warmer, but do not place a hand warmer in there yet. Record the temperature of the water bath.
2. Place a hand warmer in the ice water bath.
3. Allow a few minutes for the hand warmer to come to the same temperature as the ice water.

Note: In the following steps, be ready with a timer and the infrared thermometer to observe and record the changes that occur after crystallization is initiated. Have a helper assist you in taking readings and writing the data.

4. Remove the hand warmer from the ice water bath.
5. Place the hand warmer in a Styrofoam cup.
   - This insulates the hand warmer so that heat lost to/gained from the surface is minimized.
6. Record the starting temperature and the time in your lab notebook.
7. Snap the metal disk in the hand warmer and start the timer. Start the timer at the same time as you snap the disk.
8. Record the temperature of the hand warmer every minute for 15 minutes.

- Feel free to change the time or duration of the measurements if you choose, but be sure to use the same time/duration for each trial. For example, take the temperature every 10 seconds for the first minute and every minute for 15 minutes thereafter.

9. Remove the heat packet from the Styrofoam cup upon completion.

Crystal growth observations:

1. Place a hand warmer in the ice water bath.

2. Allow a few minutes for the hand warmer to come to the same temperature as the ice water.

3. Remove the hand warmer from the water bath.

4. Place heat packet on a flat surface (*be sure to have paper towels or newspaper underneath it to avoid burning the surface)

5. Snap the metal disk in the hand warmer and start the timer. Start the timer at the same time as you snap the disk.

6. Time how long it takes for the entire hand warmer to crystallize.

   - Watch the hand warmer carefully as the crystals form.
   - Use your judgment about when the entire contents of the hand warmer have crystallized.
   - Write down your criteria for determining that the entire contents of the hand warmer have crystallized.

7. Observe the crystals that are formed. Write all observations in your lab notebook.

   - Record their shape.
   - Record the maximum length of the crystals.
   - It will be difficult to obtain precise measurements of the crystals' length in the hand warmer since they break easily and grow into each other. Just do your best to estimate.
   - As an option, photograph or film the hand warmer during crystallization and analyze the images later. Include a ruler in the pictures so you know the scale.

#3: Experiments on hot packet at a high starting temperature

1. Heat water in the tea kettle to boiling, then remove it from the heat.

   - This water will be used to raise the temperature in the water baths.
2. Add a mixture of hot water and tap water to one Styrofoam cup so that the water level will cover a hand warmer and has a temperature around 40^{o}C, but do not place a hand warmer in there yet. Record the temperature of the hot water bath.
   - Add hot water or tap water to keep the temperature constant throughout the experiment.
3. Place a hand warmer in the hot water bath.

4. Allow a few minutes for the hand warmer to come to the same temperature as the hot water bath.

Note: In the following steps, be ready with a timer and the infrared thermometer to observe and record the changes that occur after crystallization is initiated. Have a helper assist you in taking readings and writing the data.

5. Remove the hand warmer from the hot water bath.
6. Place the hand warmer in a Styrofoam cup.
   - This insulates the hand warmer so that heat lost to the surface is minimized.
7. Record the starting temperature and the time in your lab notebook.
8. Snap the metal disk in the hand warmer and start the timer. Start the timer at the same time as you snap the disk.
9. Record the temperature of the hand warmer every minute for 15 minutes.
   - Feel free to change the time or duration of the measurements if you choose, but be sure to use the same time/duration for each trial. For example, take the temperature every 10 seconds for the first minute and every minute for 15 minutes thereafter.

10. Remove the heat packet from the Styrofoam cup upon completion.

Crystal growth observations:

1. Place a hand warmer in the hot water bath.

2. Allow a few minutes for the hand warmer to come to the same temperature as the hot water (approximately 40^{o}C).

3. Remove the hand warmer from the water bath.

4. Place heat packet on a flat surface (*be sure to have paper towels or newspaper underneath it to avoid burning the surface)

5. Snap the metal disk in the hand warmer and start the timer. Start the timer at the same time as you snap the disk.

6. Time how long it takes for the entire hand warmer to crystallize.

   - Watch the hand warmer carefully as the crystals form.
   - Use your judgment about when the entire contents of the hand warmer have crystallized.
   - Write down your criteria for determining that the entire contents of the hand warmer have crystallized.

7. Observe the crystals that are formed. Write all observations in your lab notebook.

   - Record their shape.
   - Record the maximum length of the crystals.
   - It will be difficult to obtain precise measurements of the crystals' length in the hand warmer since they break easily and grow into each other. Just do your best to estimate.

- As an option, photograph or film the hand warmer during crystallization and analyze the images later. Include a ruler in the pictures so you know the scale.

Analyzing Your Results

1. Compile results and drawings from groups working with different starting temperatures.

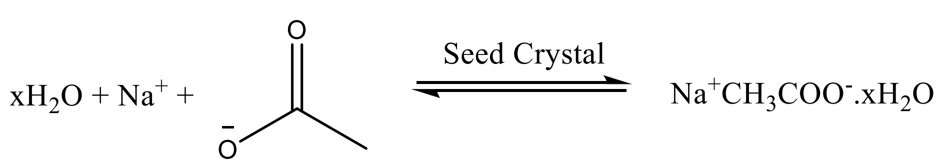
2. For the time it took to complete crystallization:
   a. Graph the *Starting Temperature* on the x-axis vs. the *Time to Complete Crystallization* on the y-axis.

3. For the temperature vs. time data:
   a. Graph the *Time* on the x-axis and the *Temperature of the Hand Warmer* on the y-axis.

4. For the length of the crystals:
   a. Graph the *Starting Temperature* on the x-axis and the *Maximum Length of the Observed Crystals* on the y-axis.

5. Discuss your results. For example, what was the maximum temperature reached for each starting temperature, and how long did it take to reach it? Does the temperature remain constant for any length of time for each of the hand warmers? Why? Which hand warmer had the longest crystals?

6. The reaction in this experiment is as followed:



Eq. 8

   Which condition (i.e. ice bath, room temperature bath or warm water bath) do you predict would be the most favorable for the forwards reaction to take place? In other words, which condition is the furthest from equilibrium?

   Hint: consider the Le Chatelier's principle.

7. Compare your prediction in question 6 with your experimental results. Is there a clear correlation between reaction temperature and rate?

8. Compare the heat transfer, q, between the heat packet originally chilled in an ice bath, and one heated in a 40ºC water bath, in the first 30 seconds of the crystallization reaction. Useful information: each heat packet contains ~ 30 mL sodium acetate tri-hydrate (i.e. $Na^+CH_3COO^-$. $3H_2O$); the density of sodium acetate tri-hydrate is 1.45 $^g/_{mL}$; the molar mass of sodium acetate tri-hydrate is 135.03 $^g/_{mol}$; the specific heat capacity of sodium acetate tri-hydrate is 229 $^J/_{mol*K}$.

   * Hint: Consider the system as only sodium acetate and water; neglect the heat packet plastic container. Assume sodium acetate and water has a ratio of 1:3. Determine the amount of sodium acetate tri-hydrate in a heat packet, and calculate heat using the equation:

   $q = n * C * (T_{30} – T_0)$

   where n = amount of sodium acetate tri-hydrate in mole;

   C = specific heat capacity of sodium acetate tri-hydrate;

   T_{30} = temperature at 30 seconds;

   T_0 = temperature at 0 second.

   Do this calculation for the heat packets chilled in the ice bath, or warmed in the hot water bath. Compare the results with your answer in 6 and 7.

Additional note: students with access to graphing calculators and/or a computer (e.g. Microsoft Excel) can import the data into such devices and generate plots. Various regressions could be used to fit the data plot, such as linear, quadratic, exponential and logarithmic.