Sub-Zero — High School Sample Classroom Task

Introduction

Chemical reactions can be described as endothermic or exothermic depending on whether energy is used or given off during a reaction. Practically, these types of reactions can be used as instant hot or cold packs at times when we need them, such as in hand warmers. In this task, students will demonstrate their knowledge of chemical reactions and energy change during the reactions. They will use molecular models to diagram the change in the arrangement of atoms and number and types of bonds before and after reactions. Following experiments where they measure the change in temperature of the reactions, they create models showing the change in energy (bond energy and thermal energy) in addition to the changes in the chemical species and number and types of bonds. Finally, students compare theoretical values for the temperature change of the reaction (given different reactant amounts) with their measured values using graphs and equations for lines of best fit and make evidence-based claims for whether the reactions they tested would be useful in hand warmers given criteria related to safety and usability.

Standards Bundle

(Standards completely highlighted in bold are fully addressed by the task; where all parts of the standard are not addressed by the task, bolding represents the parts addressed.)

<u>**CCSS-M**</u>

MP.1 **Make sense of problems and persevere in solving them.**

MP.2 **Reason abstractly and quantitatively.**

MP.3 **Make a viable argument and critique the reasoning of others.**

MP.4 **Model with mathematics.**

MP.6 **Attend to precision.**

HSN.Q.1 **Use units as a way to understand problems and to guide the solution of** multi-step **problems**; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

HSN.Q.2 **Define appropriate quantities for the purpose of descriptive modeling.**

HSN.Q.3 **Choose a level of accuracy appropriate** to limitations on measurement **when reporting quantities.**

HSA.CED.1 **Create equations** and inequalities **in one variable and use them to solve problems. Include equations arising from linear** and quadratic **functions,** and simple rational and exponential functions.

HSA.REI.3 **Solve linear equations** and inequalities **in one variable, including equations with coefficients represented by letters.**

HSS.ID.6 **Represent data on two quantitative variables on a scatter plot,** and describe how the variables are related.

HSS.ID.6a **Fit a function to the data; use functions fitted to data to solve problems in the context of the data.** Use given functions or choose a function suggested by the context. Emphasize linear, quadratic, and exponential models.

HSS.ID.6c **Fit a linear function for a scatter plot that suggests a linear association.**

HSS.ID.7 **Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.**

NGSS

HS-PS1-2 **Construct** and revise **an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table**, **and knowledge of the patterns of chemical properties.**

HS-PS1-4 **Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in** total **bond energy.**

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).**

CCSS-ELA/Literacy

RST.9-10.3 **Follow precisely a** complex **multistep procedure when carrying out experiments**, taking measurements, **or performing technical tasks**, attending to special cases or exceptions defined in the text.

W.9-10.1 **Write arguments to support claims in an analysis of substantive topics** or texts, **using valid reasoning and relevant and sufficient evidence.**

WHST.9-10.1 **Write arguments focused on *discipline-specific content*.**

W.9-10.1.a & WHST.9-10.1.a

Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, **and create an organization that establishes clear relationships among claim(s),** counterclaims, **reasons, and evidence.**

W.9-10.1.b **Develop claim(s)** and counterclaims **fairly, supplying evidence for** each while pointing out **the strengths and limitations** of both in a manner that anticipates the audience's knowledge level and concerns.

WHST.9-10.1.b **Develop claim(s)** and counterclaims **fairly, supplying data and evidence** for each **while pointing out the strengths and limitations of** both **claim(s)** and counterclaims **in a discipline-appropriate form** and in a manner that anticipates the audience's knowledge level and concerns.

W.9-10.1.c & WHST.9-10.1.c

Use words, phrases, and clauses to link the major sections of the text, create cohesion, and **clarify the relationships between claim(s) and reasons, between reasons and evidence,** and between claim(s) and counterclaims**.**

W.9-10.7 & WHST.9-10.7

Conduct short as well as more sustained **research projects to answer a question (including a self-generated question) or solve a problem**; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, **demonstrating understanding of the subject under investigation.**

WHST.9-10.2 **Write informative/explanatory texts,** including the narration of historical events, **scientific procedures/experiments, or technical processes.**

WHST.9-10.4 **Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.**

Information for Classroom Use

Connections to Instruction

The full task can be accomplished over the course of an instructional unit on thermochemistry. Task Component A checks for student understanding of (i.e., formatively assesses) chemical reactions, while Task Component B can serve as a formative assessment for use with calorimetry and the distribution of thermal energy in a system. Task Components C through G could be used as formative assessments of the embedded engineering practices and math concepts. Material covered in this task may be new for students enrolled concurrently in Algebra I and would require coordination with the mathematics teacher. For these students, the task may allow teachers and students to assess student understanding of both math and science during a coordinated unit between both content area teachers. For students who have previously taken Algebra I or if this science unit is covered after the associated math standards, parts of this task, such as Task Components E, F and G, can serve a platform for checking for understanding and application of the math concepts included in the task.

This task provides multiple interdisciplinary connections to ELA/Literacy in both research and writing argument and research. Students can demonstrate their understanding of ELA/Literacy research standards in Task Components A, B, C, D, & G, and they can demonstrate written argument on Task Components B, F, & H. This task has been aligned to the 9–10 grade band ELA/Literacy standards for research and writing argument. Teachers using this task in 11th or 12th grade should refer to the comparable CCSS for the 11–12 grade band.

Approximate Duration for the Task

The entire task could take 4–9 class periods (45–50 minutes each) spread out over the course of an instructional unit, with the divisions listed below:
Task Component A: up to 1 class period
Task Component B: 1–2 class periods
Task Components C and D: 1–2 class periods, depending on whether parts are done outside of class
Task Components E, F, G and H: 2–4 class periods total, depending on whether parts are done outside of class

Note that this timeline only refers to the approximate time a student may spend engaging in the task components, and does not reflect any instructional time that may be interwoven with this task.

Assumptions

The instructor should have a secure understanding of calorimetry. Students must be able to construct a trendline and write equations to make predictions about data. Students must also be cognizant of patterns of the periodic table as related to the state of chemical substances and related chemical reactions in Attachment 5 and 6.

Materials Needed

To do the experiments for Task Components B and C, students will need access to safety equipment, laboratory space, and reactants and calorimeters as laid out in Attachment 1.

Supplementary Resources

N/A

Accommodations for Instruction and Assessment Tasks

To accurately measure three dimensional learning of the NGSS along with CCSS for mathematics, modifications and/or accommodations should be provided during instruction and assessment for students with disabilities, English language learners, and students who are speakers of social or regional varieties of English that are generally referred to as "non-Standard English".

Classroom Task

Context

The Alaskan Bering Sea is known for producing one of the world's most prized types of seafood, the Alaskan king crab. Fishermen often endure harsh seas and bone-chilling sub-zero conditions while fishing for these creatures. Staying warm in these difficult conditions is crucial, both for them to survive and to maintain their livelihood. External warming devices, such as hand-warmers, can be very helpful to fishermen and others who face extreme cold temperatures on a regular basis. You will use what you know about electron states, chemical reactions, periodic trends and bond energy to plan a device that uses a chemical reaction to help keep a fisherman's hands warm.

Task Components

A. Using Table A in Attachment 1, select one dissolution and one chemical reaction to analyze for its ability to heat its surroundings. Create a drawing on Attachment 2 representing the molecular level of compounds before and after the chemical processes. Use your knowledge of outer electron states and patterns of chemical properties (such as the patterns in the periodic table) to construct an explanation of why the chemical reaction occurs or what chemical property leads to dissolution. *(Safety Note: Reactions involving alkali metals and water are dangerous and should not be used.)*

B. The coffee cup calorimeter is often used in lab experiments to evaluate the transfer of energy from one object to another as well as to determine the amount of energy released from a chemical process. The calorimeter is constructed by stacking two coffee cups together and placing a lid on the cups (see Reference Sheet A, Attachment 1). You need to determine whether a coffee cup calorimeter will give you accurate data about the reaction you are considering. Investigate the claim that a coffee cup calorimeter is a closed system and can be used to determine the transfer in energy between two substances, as follows: Make a prediction of the final temperature that a solution of 100 mL of 100 °C water plus 100 mL of 50 °C water would create. Perform sufficient trials of this investigation to provide reliable data, and record findings on Data Sheet B (Attachment 3). Describe the initial conditions of the calorimeter system, including the components inside the calorimeter, the calorimeter and the calorimeter's surroundings. Using the data from the investigation as evidence, construct an argument that supports or rejects the claim that a coffee cup calorimeter is a closed system. Cite evidence when supporting or refuting the claim that the system is isolated from the surroundings and describe the final system conditions at the point of highest solution temperature. *[Teacher Notes: Students will find that the calorimeter is not a perfectly isolated system. However, because thermal loss is relatively small, the calorimeter provides a simple way of collecting meaningful data for general analysis.]*

Additional Option: Quantitative analysis of energy can be completed by calculating enthalpy of energy lost or gained by the components of the system (Q lost by hot water = Q gained by calorimeter + Q gained by water in calorimeter, $Q = (C)(m)(\Delta T)$. *It can be assumed that the surrounding environment, calorimeter and initial solution in the calorimeter are at the same temperature if water is allowed to reach room temperature by sitting out overnight and that the* *highest solution temperature also is the final temperature of the calorimeter.*

C. Using the knowledge you have gained about calorimetry as way to measure thermal energy transfer, conduct an investigation to collect evidence of thermal energy release when the net bond energies change, as a means determining whether the reaction you are investigating can be used to create a hand warmer. Using the two processes selected in Task Component A, determine the temperature change generated when compounds are added to 100mL of water (solvation) or to 100mL HCl (chemical reaction) solution in the calorimeter system. Select three or more quantities of each solid compound (10 grams or less for dissolution and 1 gram or less for reactions with HCl) to test and perform a sufficient number of trials to establish validity of the results. Perform trials and record data on Data Sheet C (Attachment 4) and graph the ΔT/mass of each solid (g). Justify why you chose the quantities you selected for each reaction type.

D. Using the data from your experiment and the information provided on Reference Sheet E (Attachment 5), create models and graphs of what is happening at the molecular level to illustrate the change in energy of the system before and after the chemical reactions in your experiment occurred. Your model should show the chemical components in the system and the movement of energy within the system and between the system and the surroundings. Your graph(s) should illustrate the relative change in bond energy before and after the experiment and the relative change in thermal energy before and after the experiment. Use your graphical representations to explain the change in the energy of the chemical system (bond energy or thermal energy) from the start to the end of the experiment as the energy is released or absorbed during the chemical reaction.

E. Using Data Sheet E (Attachment 7), complete the table and graph comparing the theoretical temperature change from Reference Sheet E (Attachment 5) and the actual temperature change from your experiment. For each dataset (theoretical and experimental), write an equation for a line of best fit that can be used to predict the change in temperature based on the mass of the compound.

   Additional Option: Instead of providing students with the theoretical temperature changes on the data table provided, students could calculate them using enthalpy values listed on data table.

F. Using the data and equations from the previous components, determine whether the experimental temperature change is similar enough to the theoretical temperature change to make accurate predictions about the change in temperature of other substances not tested or other mass amounts not tested. Use evidence from the experiment and plots to support or refute your claim.

G. Temperatures in the Arctic Circle can fall well below 0 °C and can cause extreme frostbite. Fishermen wear gloves to protect their hands from the cold and use hand warmers for supplemental heat. However, temperatures above 49 °C for extended periods of time can cause severe skin burns. Assume that the starting temperature for the hand warmers in a glove is 5 °C. Use the formula written in Task Component F to determine the quantity of solids that would be needed to achieve a peak temperature of 49 °C for each compound selected.

H. Use evidence collected in Task Components A through G to make a claim stating whether the chemical process tested could be considered a viable and safe option for use as hand warmer components. The claim should take into account the process's ability to produce heat, the quantity of reactants required, and the safety of the compounds required to achieve sufficient temperature change. Cite specific data and your models as evidence to support your reasoning.

Alignment and Connections of Task Components to the Standards Bundle

Task Component A asks students to predict, model, and explain the reasoning behind the prediction of the outcome of two chemical processes (reaction and dissolution) based on an understanding of the patterns of properties and number of valence electrons following the period table. This partially addresses the NGSS performance expectation of **HS-PS1-2** (partially assessed because it does not include a revision of the explanation) through parts of (individual bullets from the Appendices) the associated core ideas of **PS1.A: Structure and Properties of Matter** and **PS1.B: Chemical Reactions,** part of the crosscutting concept of **Patterns,** and part of the practice of **Constructing and Revising Explanations.** By creating the model for the molecular-level depiction of chemical processes and describing the movement of elements within the chemical system, students partially address part of the NGSS practice of **Developing and Using Models (as it relates to HS-PS1-4)** and parts of the NGSS crosscutting concepts of **Energy and Matter (as it relates to HS-PS1-4)** and **Scale, Proportion, and Quantity.**

Task Component B asks students to investigate the transfer of thermal energy when two equal amounts of water with different temperatures are mixed and then to use that data (as well as a description of the calorimeter system) to evaluate the claim that the calorimeter is a closed system. This partially addresses **HS-PS3-4** (partially addressed because it does not ask students to plan their own investigation) through parts of the associated core ideas of **PS3.B: Conversion of Energy and Energy Transfer** and **PS3.D: Energy in Chemical Processes,** part of the crosscutting concept of **Systems and System Models,** and part of the practice of **Planning and Carrying Out Investigations.** This also partially addresses part of the NGSS crosscutting concept of **Energy and Matter.** When calculating the predicted temperature of the water and when gathering the temperature data, students demonstrate their understanding of parts of the CCSS-M content standard of **HSN.Q.3** and the CCSS-M practices of **MP. 2** and **MP.6.** By performing an investigation to collect data to investigate a claim, students are partially assessed on **RST.9-10.3**, following a multistep procedure when carrying out experiments; and on **W.9-10.7** and **WHST.9-10.7**, conducting short research projects to answer a question. By using evidence from this investigation to support or reject a claim, students can partially address on **W.9-10.1**, **W.9-10.1.a**, **W.9-10.1.b**, **W.9-10.1.c**, **WHST.9-10.1**, **WHST.9-10.1.a**, **WHST.9-10.1.b**, and **WHST.9-10.1.c**, writing arguments to support claims.

Task Components C and D ask students to conduct an investigation to collect data on the change in thermal energy of the system during the reaction and to use molecular level drawings and graphs of energy change to illustrate that the change in the temperature of the system depends on the net change in bond energy for the reaction. These partially address the NGSS performance expectation of **HS-PS1-4** by partially addressing and integrating parts of the core ideas of **PS1.A: Structure and Properties of Matter** and **PS1.B: Chemical Reactions,** and by addressing part of the practice of **Developing and Using Models** and part of the crosscutting concept of **Energy and Matter**, as these two dimensions relate to HS-PS1-4. By collecting and reporting data during the investigation, students can demonstrate their understanding of parts of the CCSS-M content standard of **HSN.Q.3,** the CCSS-M practice of **MP.6,** and part of the NGSS practice of **Planning and Carrying Out Investigations.** When using system diagrams and graphs to illustrate change in energy, students are addressing parts of the CCSS-M content standard of **HSS.ID.6** (depending on the type of graph created), the CCSS-M practices of **MP.4** and **MP.2,** and part of the NGSS crosscutting concepts of **Systems and System Models** and **Scale, Proportion, and Quantity.** Students are partially addressing **MP.1** as they conduct an investigation in **Task Component C** and make sense of the problem, and students partially address **RST.9-10.3**, following a multistep procedure when carrying out experiments; and on **W.9-10.7** and **W.11-12.7**, conducting short research projects to answer a question.

Task Components E and F ask students to graph the measured and theoretical data for the reactions, to derive equations for each from trendlines of the data, and then to compare the two types of data to address whether the theoretical data could be used to predict the results of the experiments seen in the measured data. By making the scatterplots, creating the trendlines and fitting the equations to the trendlines, students can demonstrate their understanding of parts of the CCSS-M content standards of **HSS.ID.6, HSS.ID.6a, HSS.ID.6c** and **HSA.CED.1** and the CCSS-M practices of **MP.2, MP.4** and **MP.6.** By comparing the datasets and equations, students also partially address the CCSS-M content standard of **HSS.ID.7.** By asking students to use evidence to validate or deny a claim, **Task Component F** partially addresses part of the NGSS practice **Engaging in Argument from Evidence,** and **W.9-10.1**, **W.9-10.1.a**, **W.9-10.1.b**, **W.9-10.1.c**, **WHST.9-10.1**, **WHST.9-10.1.a**, **WHST.9-10.1.b**, and **WHST.9-10.1.c**, writing arguments.

Task Components G and H ask students to calculate the amount of mass of the reactants needed for a specific temperature change ideal for hand warmers using the trendline equations and then to use these numbers with the given data and the plots produced to evaluate the usefulness of the tested reactions for use in hand warmers. This partially addresses the CCSS-M content standards of **HSA.CED.1, HSN.Q.1, HSN.Q.2** and **HSA.REI.3;** the CCSS-M practices of **MP.2, MP.4** and **MP.6**, and part of the NGSS core idea of **ETS1.B: Developing Possible Solutions.** The plots produced, the trendline equations derived, and the calculations made are all essential pieces of evidence for evaluating the use of the reactions in hand warmers, whereas the context provides an opportunity for students to use mathematical modeling and analytical reasoning to make decisions for a real-world problem with student-produced data. In **Task Component G**, by asking students to use the formula they wrote in Task Component F to answer a research questions about the quantity of solids needed, students can demonstrate their understanding of **W.9-10.7** and **WHST.9-10.7**, conducting research. By asking students to make a claim and cite specific data as evidence to support their reasoning, **Task Component H** partially addresses part of the NGSS practice **Engaging in Argument from Evidence, and W.9-10.1**, **W.9-10.1.a**, **W.9-10.1.b**, **W.9-10.1.c**, **WHST.9-10.1**, **WHST.9-10.1.a**, **WHST.9-10.1.b**, and **WHST.9-10.1.c**, writing argument. **Task Components G** and **H** ask students to evaluate the chemical reaction system based on the quantity of material used, as well as using evidence of patterns observed at multiple scales (temperature data, molecular models), together partially addressing the NGSS crosscutting concept of **Scale, Proportion, and Quantity.**

Evidence Statements

Task Component A

- Students write the outcome of the dissolution and chemical reaction processes, conserving electrons and elements (i.e., matter is not created or destroyed).
- Students create and use a molecular model for dissolution and a molecular model for a chemical reaction to visually represent the change in compounds before and after the chemical process by:
  - Identifying the following components:
    - Substances that are entering into the chemical process (reactants), including the types and number of atoms and the location of bonds between atoms.
    - Substances that are produced at the end of the chemical process, including the types and number of atoms and the location of bonds between atoms.
    - Electrons within the valence shells of the atoms, including those electrons involved in bonds between atoms.
  - Identifying the following relationships between components:
    - Transfer of electrons as bonds are broken and new bonds are formed, including the movement of electrons between atoms and broken and/or created bonds.
    - Transfer of atoms from one substance to another as substances are created or changed without a loss or gain in the number of atoms of each element.
  - Describing the relationships between the type of element(s), the state of valence electrons

in the element, and where the bonds break and form to show how the type of chemical process that occurs can be explained and predicted by the patterns in electron states and properties of atoms as seen in the patterns on the periodic table.

- In their explanation, students make a statement that describes the relationship between 1) the type of chemical process (reaction and dissolution) and expected outcome and 2) the types of elements and the numbers of associated valence electrons following the patterns in the period table.
- Students identify and describe the following evidence for the explanation:
    - The movement of elements and electrons in the model
    - A property of an element(s) as indicated by the location of that element on the periodic table (e.g., metal or nonmetal, highly reactive, etc.)
    - The number of valence electrons of an atom, as predicted by the group location on the period table
- Students describe their reasoning for connecting the evidence to the explanation, including the following:
    - The nature of the chemical process is determined by the properties of the elements, with element combinations following expected reactivity patterns from the period table (e.g., properties of reactivity; combination of Group 1 + Group 17 elements).
    - The chemical process is driven by the stability of the atoms — the valence shell is full through a loss of electrons, a gain in electrons or transfer/sharing of electrons via bonding.
    - Which elements interact within the chemical process is determined by the number of valence electrons available to gain or lose so that the elements when combined together can each reach a full valence shell.

Task Component B

- Students describe the phenomenon that they are investigating, including that they are determining whether the coffee cup calorimeter can be considered a closed system where heat energy is not transferred between the material inside the calorimeter and the surroundings.
- Students describe whether the evidence derived from their investigation supports this claim.
- Students make a prediction that the final temperature of the water, assuming no loss of thermal energy to the surroundings, will be 75 °C, and identify that this prediction is based on the understanding that the thermal energy is not lost in a closed system but becomes uniformly distributed.
- Students identify and describe the evidence needed to test the amount of energy transferred from the calorimeter to the surroundings, including:
    - comparison of the predicted temperature with the measured temperature, highlighting differences in the values as an indication of a transfer of thermal energy
    - measurement of the actual final temperature from at least three trials
- Students follow the procedures listed in the given experimental plan as described, including determining a sufficient number of trials based on the precision and accuracy of their data collection methods.
- Students describe the calorimeter system. In their description, students:
    - Describe the boundaries of the system as the boundary of the calorimeter if a closed system or the air/table around the calorimeter if not a closed system.

- Describe the initial conditions as a mixture of components of different thermal energy, one higher and one lower.
- Define the final conditions as one of the following (assuming that thermal energy cannot be destroyed but is only transferred to the surroundings):
  - If the system is closed, the final conditions are defined as a mixture of the components with the same temperature (lower/higher than the starting temperature of each component) reflecting a uniform distribution of thermal energy.
  - If the system is open, then there is an added transfer of thermal energy to the surroundings.

- Students construct an argument for or against the given claim that the calorimeter represents a closed system by including one of the following as evaluation of evidence and reasoning:
  - The system is closed because the final temperature is nearly equal to the predicted temperature, indicating that there is no significant transfer of thermal energy to the surroundings outside of the calorimeter.
  - The system is not closed because the final temperature is lower than the predicted temperature, indicating that there must be a transfer of thermal energy to the surroundings outside of the calorimeter.

Task Component C

- Students identify the question under investigation, including whether or not thermal energy is released when bonded atoms are separated during a chemical process.
- Students follow the given procedures for the experiment.
- Students collect temperature data as the basis of evidence for whether thermal energy is produced.
- Students represent the change in temperature for each mass amount on the scatterplot.
- Students specify that they chose quantities for each solid compound that would allow them to extrapolate changes that might occur if quantities became too large or too small

Task Component D

- Students create models to illustrate the change in energy of the chemical system at the molecular level by:
  - Labeling, and describing the components of the model, including:
    - The chemical species participating in the reaction, both before and after the reaction.
    - The bonds that are broken during the course of the reaction and the new bonds that are formed.
    - The relative bond energy at the start of the reaction and at the end of the reaction.
    - The relative amount of thermal energy at the start of the reaction and at the end of the reaction.
  - Describing the relationships between components of the model, including:
    - Arrows showing the movement of energy between the thermal energy of the molecules and the bond energy.
    - A change in the bond energy over the course of the experiment that reflects a reciprocal change in the thermal energy of the system (e.g., bond energy goes down and thermal energy goes up).

        - Any transfer of thermal energy to the surroundings.
    - Describing the following connections:
        - The change in energy of the system, which can be observed at a large scale, is driven by the total change in bond energy from the reactants to the products, which is reflective of changes happening at much smaller scale.
        - A change in bond energy is accompanied by a change in thermal energy of the system, reflecting a transfer of energy.
        - No energy is lost during the chemical reaction, just transformed, so that the total energy of the system remains the same.

Task Component E

- Students represent the data on the plot and include trendlines (line of best fit) for both the measured data and for the theoretical data for each reaction.
- Students write equations that represent the trendline for the measured data and the trendline for the theoretical data for each reaction.

Task Component F

- Students make a claim that includes that the experimental temperature change is similar enough to the theoretical temperature change to make accurate predictions.
- Students support the claim by identifying and describing evidence, including the similarities between the locations of the experimental points with the theoretical points and/or the similarities between the slope and intercept of the equations for the trendlines.
- Students describe the relevance of the evidence to the claim
- Students synthesize the evidence and their evaluations, including reasoning that because the data points/trendlines are so similar, the predicted numbers are likely to be close enough to the measured numbers in a new experiment of different amounts or different reactions.

Task Component G

- Students create equations from the trendlines and correctly use them to solve for mass to achieve the temperature change for a maximum of 49 °C for each substance tested.

Task Component H

- Students make a claim that includes that the chemical process is or is not a viable and safe option for use in hand warmers.
- Students identify and describe the following as evidence:
    - The change in temperature values using the trend line equation and/or trends in the data from the plot
    - The amount of mass, or quantity of material, required to cause the temperature change as calculated using the trend line equation.
- Students evaluate and synthesize the evidence using any of the following lines of reasoning:
    - The reaction creates too low of a temperature change to be useful as a hand warmer with any mass of reactant.
    - The reaction creates too high of a temperature change to be safe as a hand warmer even with small amounts of reactant.

  - A reasonable temperature change requires too much reactant to be practically used as a hand warmer.
  - The change in temperature is reasonable—that is, not too high or too low given a range in reactant amounts that are practical for use in a hand warmer.
- In their evaluation, reasoning, and synthesis, students cite their molecular models as further evidence, describing how patterns observed at the molecular scale serve as evidence for why the reactants behaved as they did.

Attachment 1. Reference Sheet A

Table A

ammonium nitrate + water
calcium chloride anhydrous + water
lithium chloride + water
sodium acetate + water
sodium chloride + water
sodium carbonate + water
magnesium sulfate anhydrous + water
magnesium + 3M hydrochloric acid
magnesium oxide + 3M hydrochloric acid

Calorimeter Diagram

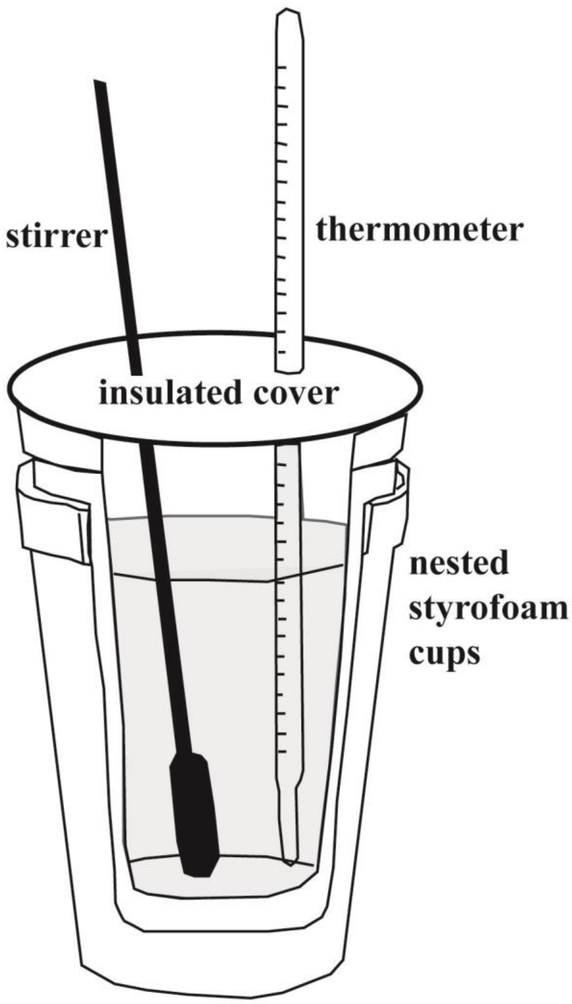

Image above is derived from the following source:
www.sparknotes.com/testprep/books/sat2/chemistry/chapter11section4.rhtml
Last accessed: April 2014

Attachment 2. Data Sheet A

Molecular Model System Diagram Compounds:

Before	After

Model features should include:

- The chemical reaction, the system and the surroundings under study
- The bonds that are broken during the course of the process
- The bonds that are formed during the course of the process
- The energy transfer between the system and surroundings

Explanation:____

Attachment 2. (continued) **Data Sheet A**

Molecular Model System Diagram Compounds:

Before	After

Model features should include:

- The chemical reaction, the system and the surroundings under study
- The bonds that are broken during the course of the process
- The bonds that are formed during the course of the process
- The energy transfer between the system and surroundings

Explanation:____

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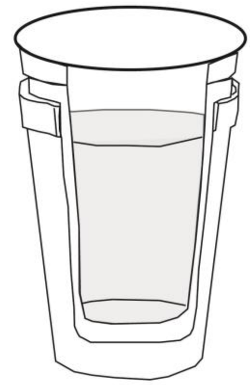
Attachment 3. Data Sheet B

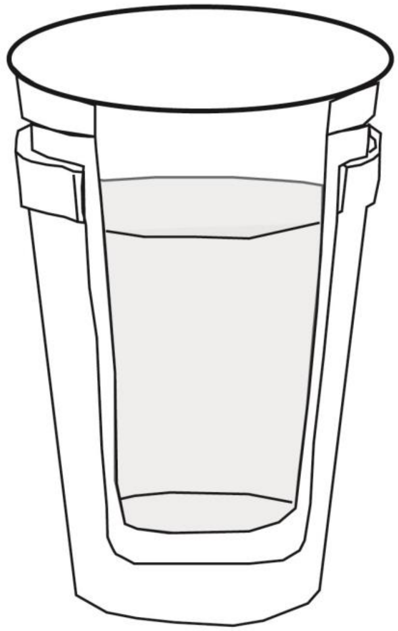
100mL of 100 °C water	+	100mL of 50 °C water	=	Predicted Final Temperature	Trial 1 Actual Final Temperature	Trial 2 Actual Final Temperature	Trial 3 Actual Final Temperature

Describe your reasoning for your predicted final temperature:

Stating **evidence** from your investigation, explain how the data support or do not support the prediction:

Attachment 3. (continued) **Data Sheet B**

Initial System Diagram  Compound Calorimeter
Description

Final System Diagram

Description

Attachment 4. Data Sheet C

Data Table C-1

Compounds	Mass of Compound (g)	Initial Tempera-ture	Final Tempera-ture	ΔTempera-ture	ΔT/mass of Compound (g)
Trial 1					
Trial 2					
Trial 3					

Data Table C-2

Compounds	Mass of Compound (g)	Initial Tempera-ture	Final Tempera-ture	ΔTempera-ture	ΔT/mass of compound (g)
Trial 1					
Trial 2					
Trial 3					

Attachment 4. (continued) **Data Sheet C**

C-1 Graph

C-2 Graph

Attachment 5. Reference Sheet E: Student Version

	Molar Mass (g/mol)	ΔH (Kj/mol)	3 g	5 g	10 g
Magnesium Sulfate $MgSO_4$	120.366	-87.4	.0249 mol q= - 2.18Kj Calc. ΔT=5.05 ^{0}C	.0415 mol q= - 3.63 Kj Calc. ΔT= 7.88^{0}C	.0831 mol q= - 7.26 Kj Calc. ΔT=15.8^{0}C
Ammonium Nitrate NH_4NO_3	80.052	25.69	.0375 mol q= .963 Calc.ΔT -2.23^{0}C	.0625 mol q= 1.61 Calc.ΔT=-3.66^{0}C	.125 mol q= 3.2 Calc. ΔT=-6.95^{0}C
Calcium chloride anhydrous $CaCl_2$	110.98	-70.2	.0270 mol q= - 1.90 Kj CalcΔT= 4.39^{0}C	.0451 mol q= - 3.17Kj CalcΔT= 7.21^{0}C	.0901 mol q= - 6.33Kj CalcΔT= 13.7^{0}C
Lithium chloride LiCl	42.394	-37.0	.0708 mol q= - 2.618Kj Calc. ΔT= 6.07^{0}C	.118 mol q= - 4.37Kj Calc. ΔT= 9.94^{0}C	.236 mol q= - 8.73 Kj Calc. ΔT= 19.0^{0}C
sodium acetate $NaC_2H_3O_2$	82.0343	-17.4	.0366 mol q= - .637Kj Calc. ΔT=1.48^{0}C	.0610 mol q= - 1.06Kj Calc. ΔT=2.41^{0}C	.122 mol q= - 2.12Kj Calc. ΔT=4.60^{0}C
sodium chloride NaCl	58.44	+3.87	.0513 mol q= .199Kj Calc. ΔT= -.460^{0}C	.0856 mol q= .331Kj Calc. ΔT=-.753^{0}C	.171 mol q= .662Kj Calc. ΔT= -1.44^{0}C
Sodium carbonate	105.9885	-29.0	.0283 mol q = -.821Kj Calc. ΔT= 1.90^{0}C	.0471 mol q= -1.37Kj Calc. ΔT=3.11^{0}C	.0946 mol q= -2.74Kj Calc. ΔT=5.96^{0}C
magnesium + 3M hydrochloric acid	24.305	-440	.123 mol q= - 54.3Kj Calc. ΔT=100+^{0}C	.206 mol q= - 90.5Kj Calc. ΔT=100+^{0}C	.411 mol q= - 181Kj Calc. ΔT=100+^{0}C

magnesium oxide + 3M hydrochloric acid	40.3044	-151	.0744 mol q= - 11.72Kj Calc. ΔT=26.1^{0}C	.124 mol q= - 18.7Kj Calc. ΔT=42.6^{0}C	.248 mol q= - 37.4Kj Calc. ΔT=65.6^{0}C
	Molar Mass (g/mol)	ΔH (Kj/mol)	0.5 g	1 g	2 g
magnesium + 3M hydrochloric acid	24.305	-440	.026 mol q= - 9.5Kj Calc. ΔT=21.4^{0}C	.0411 mol q= - 18.1Kj Calc. ΔT=42.8^{0}C	.0822 mol q= - 36.2Kj Calc. ΔT=85.6^{0}C
magnesium oxide + 3M hydrochloric acid	40.3044	-151	.0124 mol q= - 1.87Kj Calc. ΔT=4.43^{0}C	.0248 mol q= - 3.74Kj Calc. ΔT= 8.86^{0}C	.0496 mol q= - 7.48Kj Calc. ΔT=17.5^{0}C

Attachment 6. Reference Sheet E: Teacher Version

	Molar Mass (g/mol)	ΔH (Kj/mol)	3 g	5 g	10 g
Magnesium Sulfate $MgSO_4$	120.366	-87.4	.0249 mol q= - 2.18Kj Calc. ΔT=5.05^{0}C Exp. ΔT= 5.78^{0}C	.0415 mol q= - 3.63 Kj Calc. ΔT= 7.88^{0}C Exp. ΔT= 9.8^{0}C	.0831 mol q= - 7.26 Kj Calc. ΔT=15.8^{0}C Exp. ΔT= 15.43^{0}C
Ammonium Nitrate NH_4NO_3	80.052	25.69	.0375 mol q= .963 Calc.ΔT -2.23^{0}C Exp. ΔT= -2.3^{0}C	.0625 mol q= 1.61 Calc.ΔT=-3.66^{0}C Exp.ΔT=-3.7^{0}C	.125 mol q= 3.2 Calc. ΔT=-6.95^{0}C Exp. ΔT= -6.6^{0}C
Calcium chloride anhydrous $CaCl_2$	110.98	-70.2	.0270 mol q= - 1.90 Kj CalcΔT= 4.39^{0}C Exp. ΔT=3.67^{0}C	.0451 mol q= - 3.17Kj CalcΔT= 7.21^{0}C Exp. ΔT=6.5^{0}C	.0901 mol q= - 6.33Kj CalcΔT= 13.7^{0}C Exp. ΔT=12.67^{0}C
Lithium chloride LiCl	42.394	-37.0	.0708 mol q= - 2.618Kj Calc. ΔT= 6.07^{0}C Exp. ΔT=5.7^{0}C	.118 mol q= - 4.37Kj Calc. ΔT= 9.94^{0}C Exp. ΔT=8.94^{0}C	.236 mol q= - 8.73 Kj Calc. ΔT= 19.0^{0}C Exp. ΔT=21.7^{0}C
sodium acetate $NaC_2H_3O_2$	82.0343	-17.4	.0366 mol q= - .637Kj Calc. ΔT=1.48^{0}C Exp. ΔT=1.44^{0}C	.0610 mol q= - 1.06Kj Calc. ΔT=2.41^{0}C Exp. ΔT=2.7^{0}C	.122 mol q= - 2.12Kj Calc. ΔT=4.60^{0}C Exp. ΔT=4.3^{0}C
sodium chloride NaCl	58.44	+3.87	.0513 mol q= .199Kj Calc. ΔT= -.46^{0}C Exp. ΔT=-.61^{0}C	.0856 mol q= .331Kj Calc. ΔT=-.753^{0}C Exp. ΔT=-.94^{0}C	.171 mol q= .662Kj Calc. ΔT= -1.44^{0}C Exp. ΔT=-1.44^{0}C
Sodium carbonate	105.9885	-29.0	.0283 mol q = -.821Kj Calc. ΔT= 1.9^{0}C Exp. ΔT=1.6^{0}C	.0471 mol q= -1.37Kj Calc. ΔT=3.11^{0}C Exp. ΔT=2.98^{0}C	.0946 mol q= -2.74Kj Calc. ΔT=5.96^{0}C Exp. ΔT=5.83^{0}C

magnesium + 3M hydrochloric acid	24.305	-440	.123 mol q= - 54.3Kj Calc. ΔT=100+^{0}C 5g & above Mg +HCl	.206 mol q= - 90.5Kj Calc. ΔT=100+^{0}C Generates excessive heat	.411 mol q= - 181Kj Calc. ΔT=100+^{0}C Do not attempt these are Dangerous
	Molar Mass (g/mol)	ΔH (Kj/mol)	3 g	5 g	10 g
magnesium oxide + 3M hydrochloric acid	40.3044	-151	.0744 mol q= - 11.72Kj Calc. ΔT=26.1^{0}C Exp. ΔT=26.1^{0}C	.124 mol q= - 18.7Kj Calc. ΔT=42.6^{0}C Exp. ΔT=41.9^{0}C	.248 mol q= - 37.4Kj Calc. ΔT=65.6^{0}C Exp. ΔT=63.3^{0}C
	Molar Mass (g/mol)	ΔH (Kj/mol)	0.5 g	1 g	2 g
magnesium + 3M hydrochloric acid	24.305	-440	.026 mol q= - 9.5Kj Calc. ΔT=21.4^{0}C Exp. ΔT=20.9^{0}C	.0411 mol q= - 18.1Kj Calc. ΔT=42.8^{0}C Exp. ΔT=39.9^{0}C	.0822 mol q= - 36.2Kj Calc. ΔT=85.6^{0}C Exp. ΔT=82.3^{0}C
magnesium oxide + 3M hydrochloric acid	40.3044	-151	.0124 mol q= - 1.87Kj Calc. ΔT=4.43^{0}C Exp. ΔT=4.6^{0}C	.0248 mol q= - 3.74Kj Calc. ΔT= 8.86^{0}C Exp. ΔT=9.1^{0}C	.0496 mol q= - 7.48Kj Calc. ΔT=17.5^{0}C Exp. ΔT=18.1^{0}C

Attachment 7. Data Sheet E

Compound __________________________

Amount	Theoretical Change (from Reference Sheet E)

Amount	Experimental Change

Equation for line of best fit of theoretical change __________________________________

Equation for line of best fit of experimental change ________________________________

Attachment 7. (continued) **Data Sheet E**

Compound ___________________________

Amount	Theoretical Change (from Reference Sheet E)

Amount	Experimental Change

Equation for line of best fit of theoretical change __________________________________

Equation for line of best fit of experimental change ______________________________

Summary Page