64 LN Is Cool Stuff

Purpose

To determine the specific heat of brass and the heat of vaporization of nitrogen

Required Equipment/Supplies

liquid nitrogen (Dewar flask required)
balance scale, digital preferred
50-g metal specimen, brass preferred
stopwatch
4 plastic foam cups
thermometer (to measure room temperature)

Discussion

The law of energy conservation is taught in every physics course nowadays, but in the 1700s it was unknown. It was at that time the American physicist Count Rumford in Bavaria performed experiments with heat. It makes sense that when heat is added to a substance, the temperature of the substance increases. Less noticed for many years is the *latent heat* that, *without* increasing the temperature, goes into breaking bonds between atoms when a substance changes phase. This experiment demonstrates Rumford's work on heat using some *really* cool stuff—liquid nitrogen!

CAUTION: *Liquid nitrogen is extremely cold—196°C below zero! Be careful not to spill it and make sure it does not come into contact with the skin. Only the teacher should transfer samples of liquid nitrogen.*

Part A: Determining the Evaporation Rate of LN

Procedure

Step 1: First, measure the mass of the empty cups—one placed inside the other as shown—so that you can determine the mass of the liquid nitrogen (LN) added to them.

mass of cups, m = ______________ g

Step 2: To determine the rate of evaporation of liquid nitrogen, ask the teacher to pour approximately 180 – 200 grams of LN into two plastic foam cups. After measuring its precise mass using a balance, immediately start a stopwatch and time how long it takes 10 grams to evaporate. This is very easy to observe with a digital balance. However, if using a Harvard Trip balance a convenient method of doing this is to set your balance for 10 grams *less* than the initial amount and watch for the balance arm to swing upwards. For example, if your initial amount of liquid nitrogen is 190 grams, set your balance to 180 grams and measure the time for the scale to balance again. Record the time it takes 10 grams of liquid nitrogen to evaporate.

time, $t =$ ______ s

Step 3: Calculate the rate of evaporation by dividing the mass by the time it took to evaporate.

rate of evaporation, $r =$ __________ g/s

Part B: Determining the Specific Heat of a Specimen

Procedure

Step 4: Immediately after 10 grams of liquid nitrogen have evaporated, place a 50-gram metal specimen in the LN (liquid nitrogen) and start the stopwatch. Assume the initial temperature of the metal mass is room temperature. After several minutes of rapid boiling, the rapid boiling of the LN will subside and become "quiet" as the LN and the specimen reach thermal equilibrium. Remove the specimen and measure the mass of the remaining LN. Record your data below.

$T_{initial} =$ ______ °C

initial mass of LN + cups, $m_{initial} =$ __________ g

final mass of LN + cups, $m_{final} =$ __________ g

total mass of LN that evaporated: $m_{total} =$ ________ g

time that specimen was in the cup, $t =$ __________ s

Step 5: Use the rate of evaporation calculated in Step 3 and the time measured in Step 4 to determine the mass of nitrogen that would have evaporated during the same amount of time had you *not* put the specimen in the cup. Show your calculations.

mass due to evaporation = (rate of evaporation)(time)

$$= rt$$

mass due to evaporation, $m_{evap} =$ __________ g

Name Period Date

Step 6: The total mass of LN that evaporates while the specimen is in the cup is the mass of LN that cools the specimen plus the mass of LN that would have evaporated in the same time without having placed the metal specimen in the cups.

mass of LN that evaporates = (mass of LN to cool specimen) + (mass due to evaporation)

But the total mass of LN that evaporates while the specimen is in the cup is also the difference between the initial and final masses as measured in Step 4.

(initial mass – final mass) = (mass of LN to cool specimen) + (mass due to evaporation)

Therefore, the mass of LN that cools the specimen is the difference between the initial and final masses less the amount that would have evaporated.

mass of LN to cool specimen = (initial mass – final mass) – (mass due to evaporation)

Calculate the mass of liquid nitrogen that evaporated to cool the metal specimen. Show your calculations.

mass of LN that cools specimen, m_{LN} = __________ g

Step 7: The heat the specimen loses, which is the product of its mass, specific heat, and change in temperature ($m_s c_s \Delta t$) equals the heat that cooled the specimen and caused the LN to evaporate ($m_{\mathrm{LN}} L_v$), where L_v is used for the latent heat of vaporization. Therefore,

$$m_s c_s \Delta T = m_{\mathrm{LN}} L_v$$

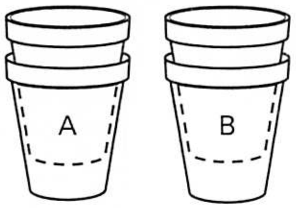
If the heat of vaporization for LN is, $L_v = 47.5$ cal/g, determine the specific heat of the metal specimen. Assume the specimen was originally at room temperature and was cooled down to the temperature at which LN boils, –196°C. Show your calculations.

c_s = __________ $\frac{\text{cal}}{\text{g}\,^\circ\text{C}}$

Part C: Determining the Heat of Vaporization of Nitrogen

Procedure

In Part A, you determined the specific heat of a sample by assuming the latent heat of vaporization for nitrogen, $L_v = 47.5$ cal/g. In this experiment, you will combine LN and warm water, and measure the temperature decrease of the water as the LN bubbles and boils away. This will enable you to calculate the latent heat of vaporization.



Step 8: Make two double-cup containers by nesting one plastic foam cup inside one inside the other as shown. Label one combination "A" and the other "B." Carefully measure the mass of containers.

mass of container A, m_A = ___________ g

mass of container B, m_B = ___________ g

Step 9: Pour about 60–75 grams of warm (about 60°C) water in cup A. Measure and record its mass. Calculate the mass of the water by subtracting the mass of the cup you measured in Step 1. Then measure the initial temperature of the hot water and remove the thermometer.

mass of container A+ mass of water, $m_{A + water}$ = ___________ g

mass of water in A, m_{water} = ___________ g

initial temperature of the water, T_i ___________ °C

Step 10: Ask the teacher to pour about 40 grams of LN into cup B. To minimize the mass loss due to evaporation of LN, *quickly* measure the mass of cup B (containing LN) and pour the LN into cup A (containing warm water). This will generate a large white cloud. (What is it?) Measure the time it takes to evaporate and calculate the mass of LN as you did for the water in Step 2.

CAUTION: *Be careful not to add so much LN that it causes the water to* freeze. *If* all *of the water freezes, it will invalidate your data because this experiment does not take into account the latent heat of fusion for water. If it does, start over and repeat Step 3. The water should be* cooled *by the LN, but* not *frozen by it.*

mass of cups B + mass of LN, $m_{B + LN}$ = ___________ g

mass of LN in B, m_{LN} = ___________ g

time to evaporate, t = ___________ s

Step 11: When evaporation of the nitrogen is complete, gently stir the water with the thermometer until all the ice, if any, has melted. Measure and record the final temperature of the water.

final temperature of the water, T_f= ___________ °C

Assuming the heat that evaporated the LN cooled the water, determine the heat of vaporization for nitrogen, L_v. Be sure your calculations take into account the amount of LN that would have evaporated while the water was being cooled as you did in Step 2, Part A. Show all your calculations.

L_v = ___________ cal/g

Name Period Date

Analysis

1. How does your value for L_v compare with the accepted value of 47.5 cal/g?

2. In Step 3 of Part B, you were cautioned against adding so much LN that it would cause some of the water to freeze. Why would this invalidate your calculations?

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Purpose

To determine the specific heat of brass and the heat of vaporization of nitrogen

Setup: 1
Lab Time: >1
Learning Cycle: concept development
Conceptual Level: moderate
Mathematical Level: easy

Required Equipment/Supplies

liquid nitrogen (Dewar flask required)
balance scale, digital preferred
50-g metal specimen, brass preferred
stopwatch
4 plastic foam cups
thermometer (to measure room temperature)

Discussion

The law of energy conservation is taught in every physics course nowadays, but in the 1700s it was unknown. It was at that time the American physicist Count Rumford in Bavaria performed experiments with heat. It makes sense that when heat is added to a substance, the temperature of the substance increases. Less noticed for many years is the *latent heat* that, *without* increasing the temperature, goes into breaking bonds between atoms when a substance changes phase. This experiment demonstrates Rumford's work on heat using some *really* cool stuff—liquid nitrogen!

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Part A: Determining the Evaporation Rate of LN

Procedure

Step 1: First, measure the mass of the empty cups—one placed inside the other as shown—so that you can determine the mass of the liquid nitrogen (LN) added to them.

mass of cups, m = ____________ g

Step 2: To determine the rate of evaporation of liquid nitrogen, ask the teacher to pour approximately 180 – 200 grams of LN into two plastic foam cups. After measuring its precise mass using a balance, immediately start a stopwatch and time how long it takes 10 grams to evaporate. This is very easy to observe with a digital balance. However, if using a Harvard Trip balance a convenient method of doing this is to set your balance for 10 grams *less* than the initial amount and watch for the balance arm to swing upwards. For example, if your initial amount of liquid nitrogen is 190 grams, set your balance to 180 grams and measure the time for the scale to balance again. Record the time it takes 10 grams of liquid nitrogen to evaporate.

time, t = _______ s

Step 3: Calculate the rate of evaporation by dividing the mass by the time it took to evaporate.

rate of evaporation, r = ___________ g/s

Part B: Determining the Specific Heat of a Specimen

Procedure

Step 4: Immediately after 10 grams of liquid nitrogen have evaporated, place a 50-gram metal specimen in the LN (liquid nitrogen) and start the stopwatch. Assume the initial temperature of the metal mass is room temperature. After several minutes of rapid boiling, the rapid boiling of the LN will subside and become "quiet" as the LN and the specimen reach thermal equilibrium. Remove the specimen and measure the mass of the remaining LN. Record your data below.

$T_{initial}$ = _______ °C

initial mass of LN + cups, $m_{initial}$ = ___________ g

final mass of LN + cups, m_{final} = ___________ g

total mass of LN that evaporated: m_{total} = _________ g

time that specimen was in the cup, t = ___________ s

Step 5: Use the rate of evaporation calculated in Step 3 and the time measured in Step 4 to determine the mass of nitrogen that would have evaporated during the same amount of time had you *not* put the specimen in the cup. Show your calculations.

mass due to evaporation = (rate of evaporation)(time)

$= rt$

mass due to evaporation, m_{evap} = ___________ g

Step 6: The total mass of LN that evaporates while the specimen is in the cup is the mass of LN that cools the specimen plus the mass of LN that would have evaporated in the same time without having placed the metal specimen in the cups.

mass of LN that evaporates = (mass of LN to cool specimen) + (mass due to evaporation)

But the total mass of LN that evaporates while the specimen is in the cup is also the difference between the initial and final masses as measured in Step 4.

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Therefore, the mass of LN that cools the specimen is the difference between the initial and final masses less the amount that would have evaporated.

mass of LN to cool specimen = (initial mass – final mass) – (mass due to evaporation)

Calculate the mass of liquid nitrogen that evaporated to cool the metal specimen. Show your calculations.

mass of LN that cools specimen, m_{LN} = ____________ g

Step 7: The heat the specimen loses, which is the product of its mass, specific heat, and change in temperature ($m_s c_s \Delta t$) equals the heat that cooled the specimen and caused the LN to evaporate ($m_{LN} L_v$), where L_v is used for the latent heat of vaporization. Therefore,

$$m_s c_s \Delta T = m_{LN} L_v$$

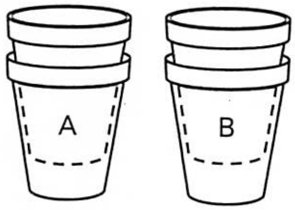
If the heat of vaporization for LN is, $L_v = 47.5$ cal/g, determine the specific heat of the metal specimen. Assume the specimen was originally at room temperature and was cooled down to the temperature at which LN boils, –196°C. Show your calculations.

$c_s =$ ____________ $\frac{\text{cal}}{\text{g}^\circ\text{C}}$

Part C: Determining the Heat of Vaporization of Nitrogen

Procedure

In Part A, you determined the specific heat of a sample by assuming the latent heat of vaporization for nitrogen, $L_v = 47.5$ cal/g. In this experiment, you will combine LN and warm water, and measure the temperature decrease of the water as the LN bubbles and boils away. This will enable you to calculate the latent heat of vaporization.



Step 8: Make two double-cup containers by nesting one plastic foam cup inside one inside the other as shown. Label one combination "A" and the other "B." Carefully measure the mass of containers.

mass of container A, m_A = ____________ g

mass of container B, m_B = ____________ g

Step 9: Pour about 60–75 grams of warm (about 60°C) water in cup A. Measure and record its mass. Calculate the mass of the water by subtracting the mass of the cup you measured in Step 1. Then measure the initial temperature of the hot water and remove the thermometer.

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mass of water in A, m_{water} = ____________ g

initial temperature of the water, T_i ____________ °C

Step 10: Ask the teacher to pour about 40 grams of LN into cup B. To minimize the mass loss due to evaporation of LN, *quickly* measure the mass of cup B (containing LN) and pour the LN into cup A (containing warm water). This will generate a large white cloud. (What is it?) Measure the time it takes to evaporate and calculate the mass of LN as you did for the water in Step 2.

CAUTION: *Be careful not to add so much LN that it causes the water to* freeze. *If* all *of the water freezes, it will invalidate your data because this experiment does not take into account the latent heat of fusion for water. If it does, start over and repeat Step 3. The water should be* cooled *by the LN, but* not *frozen by it.*

mass of cups B + mass of LN, $m_{B + LN}$ = ____________ g

mass of LN in B, m_{LN} = ____________ g

time to evaporate, t = ____________ s

Step 11: When evaporation of the nitrogen is complete, gently stir the water with the thermometer until all the ice, if any, has melted. Measure and record the final temperature of the water.

final temperature of the water, T_f= ____________ °C

Assuming the heat that evaporated the LN cooled the water, determine the heat of vaporization for nitrogen, L_v. Be sure your calculations take into account the amount of LN that would have evaporated while the water was being cooled as you did in Step 2, Part A. Show all your calculations.

L_v = ____________ cal/g

Name Period Date

Analysis

1. How does your value for L_v compare with the accepted value of 47.5 cal/g?

   Values for L_V should compare favorably.

2. In Step 3 of Part B, you were cautioned against adding so much LN that it would cause some of the water to freeze. Why would this invalidate your calculations?

   When water freezes, it releases 80 calories per gram because of the heat of fusion. If the amount of ice is small enough, it melts and absorbs the energy it released from the remaining water. This will invalidate the data, as the latent heat of fusion for the water was *not* taken into account.