Specific and Latent Heats*

Objectives

- ❑ Apply the definitions of specific heat and latent heat of fusion
- ❑ Determine the specific heat and latent heat of fusion of water
- ❑ Use calorimetry method to check that energy is conserved during the transfer of heat

Introduction

Specific Heat of Water

Specific heat is defined by the amount of heat needed to raise the temperature of 1 gram of a substance 1 degree Celsius (°C). Water has a high specific heat capacity which we'll refer to as simply "heat capacity. It means that it takes more energy to increase the temperature of water compared to other substances. The high heat capacity of water has a great deal to do with regulating extremes in the environment. For instance, he high heat capacity of water helps regulate the rate at which air changes temperature, which is why the temperature change between seasons is gradual rather than sudden, especially near the oceans. Also, the oceans and lakes help regulate the temperature ranges that billions of people experience in their towns and cities. Water surrounding or near cities take longer to heat up and longer to cool down than do land masses, so cities near the oceans will tend to have less change and less extreme temperatures than inland cities. This property of water is one reason why states on the coast and in the center of the United States can differ so much in temperature patterns. A Midwest state, such as Nebraska, will have colder winters and hotter summers than Oregon, which has a higher latitude but has the Pacific Ocean nearby.

The specific heat is defined by the equation,

$$Q = mc\Delta T \tag{1}$$

where Q is the heat transferred to the material, m is the mass of the material, c is the specific heat (i.e., the heat capacity per gram), and ΔT is the change in temperature that is the result of the heat transfer.

Latent Heat of Fusion of Water

Closely related to water's unusually high heat capacity are its high latent heat of melting and latent heat of vaporization. A solid converts to a liquid at a temperature called its freezing point and a liquid is changed to a gas at a temperature defined as its boiling point.

*Based on a lab manual developed by Prof. Mark Schlossman, Department of Physics, University of Illinois at Chicago

When changing the state of any substance, there may be no increase of temperature at that point where a change of state occurs even though heat is continuously being added. All the heat energy is being used to break all of the bonds (e.g. between polar water molecules) required to complete the change of state. The heat that is added to 1 g of a substance at the melting point to break the required bonds to complete the change of state from solid to liquid is the latent heat of fusion (or melting). The heat applied to effect a change of state at the boiling point is the latent heat of vaporization.

The amount of heat required to convert 1 g of ice to 1 g of water, 80 Cal, is termed the latent heat of melting, and it is higher for water than for any other commonly occurring substance.

The latent heat of fusion is defined by the equation,

$$Q = mL_F \tag{2}$$

where Q is the amount of transferred heat that is required to melt a solid at its melting temperature and L_F is the latent heat of fusion.

Error Analysis

Resolution and Accuracy: In this lab you will be asked to estimate the error on quantities that you measure, as well as quantities that you calculate from the measured values. You will measure the mass and temperature of various objects. Both the *resolution* and the *accuracy* of a measurement will contribute to its error. The *resolution* of a measurement refers to the ability of the measuring device to resolve a certain value. For example, if a thermometer is marked with a series of lines spaced by 1 degree, then you may be able to reliably read the temperature with a ¼ degree error, but not much better than that. You will need to determine the resolution of the scale on the measuring device. The *accuracy* of a measurement refers to the extent to which your measuring device has been calibrated against a standard. For example, if you weigh a standard mass of 100 grams, does the weighing scale read 100 grams? If not, can you correct for the inaccuracy of your weighing scale? There will be a set of standard weights in the lab room that can be used to check the accuracy of your weighing scale. Unfortunately, it is harder to test the accuracy of your thermometers and you will just have to assume that their accuracy is much better than your ability to read the thermometer.

To summarize, errors on weighing masses will be determined by both the accuracy of the scale and its resolution. Errors on reading temperatures will be determined by the resolution of the thermometer.

Propagating Errors: The term "propagating errors" refers to the determination of an error on a combination of two or more measured quantities, each with their known errors. For example, you may want to determine the error on the difference, ΔT, of two measured temperatures, say, $\Delta T = T_1 - T_2$, when you know the error σ_1 on T_1 (that is, you have determined that the measured temperature is) and you know the error σ_2 on T_2. Then, the error $\sigma_\Delta$on ΔT is given by $\sigma_\Delta = \sqrt{\sigma_1^2 + \sigma_2^2}$. This means that you have determined the difference in temperature to be $\Delta T \pm \sigma_\Delta$.

The same expression is valid for the sum of two temperatures, say $T_{sum} = T_1 + T_2$, then $\sigma_{sum} = \sqrt{\sigma_1^2 + \sigma_2^2}$, so that you have determined the sum to be $T_{sum} \pm \sigma_{sum}$.

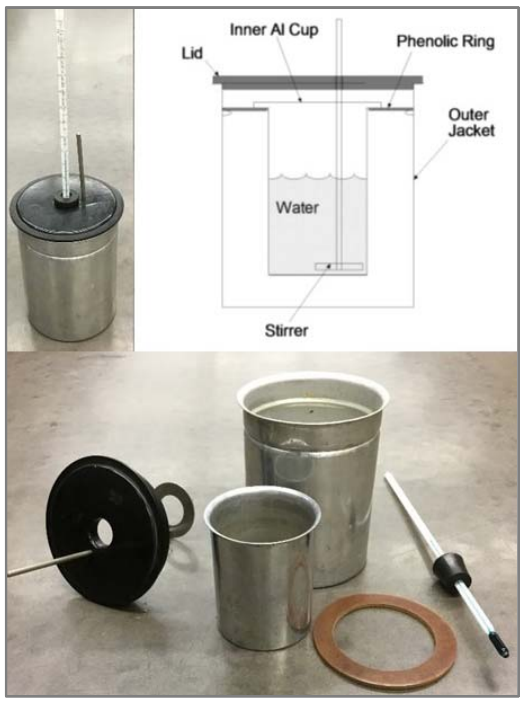
Similar rules apply to other mathematical operations, as summarized by the following table.

Mathematical Operation		**Propagation of Errors**
Addition of Subtraction	$u = x + y$ or $u = x + y$	$\sigma_u = \sqrt{\sigma_x^2 + \sigma_y^2}$
Multiplication by a Constant	$u = Ax$	$\sigma_u = A\sigma_x$
Division by a Constant	$u = \frac{x}{A}$	$\sigma_u = \frac{\sigma_x}{A}$
Multiplication or Division	$u = xy$ or $u = \frac{x}{y}$	$\left(\frac{\sigma_u}{u}\right) = \sqrt{\left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2}$

Equipment

The figure to the right shows the construction of the basic calorimeter. The calorimeter is designed to minimize heat flow between the inner cup and the outside world:

- Conduction of heat is eliminated by supporting the inner cup only by the thin, insulating phenolic (a type of plastic) ring, and by providing an insulating air space around the cup.
- Convection is eliminated by blocking air circulation with the solid ring and the lid.
- Radiation is eliminated by making the inner cup and outer jacket out of aluminum, which is mirror-bright to infrared radiation.



Specific and Latent Heats
(Experimental Procedure and Data Analysis)

This part of the lab must be completed entirely independently of your lab partner(s) or other students. Make sure that you avoid unauthorized collaboration and plagiarism. All suspected violations of the Standards of Conduct will be referred to Student Judicial Affairs.

Lab Section (Day & Time): ____________________

Name: ____ Station#: ________

Experiment 1. Specific Heat of Water

In this experiment you will check that energy is conserved during the transfer of heat. This will be done by adding hot water to cold water and measuring the final equilibrium temperature. This process can be described by the equation

$$Q_{T\to T_{cw}} = m_{cw}c_w(T - T_{cw}) = m_{hw}c_w(T_{hw} - T) = Q_{T_{hw}\to T} \tag{3}$$

where
m_{cw} = mass of cold water
c_w = specific heat of water (~ 4.186 J/g °C over the range 0 °C to 100 °C)
m_{hw} = mass of hot water
T_{cw} = initial temperature of cold water in calorimeter
T_{hw} = initial temperature of hot water
T = final temperature
$Q_{T\to T_{cw}}$ = heat absorbed by cold water at T_{cw} to reach the final temperature, T.
$Q_{T_{hw}\to T}$ = transferred from the hot water at T_{hw} to the cold water at T_{cw} until the water in calorimeter reaches the final equilibrium temperature, T.

The left side of the Eq. (3) represents the heat transferred to the cold water and calorimeter; the right side represents the heat lost by the hot water.

1. Measure the mass of the empty calorimeter, M_c, and record its value in Table 1.

2. Add approximately 100mL of cold water (less than 10°C) to the calorimeter.

3. Measure the mass of the calorimeter and the cold water, M_{c+cw}, and determine the mass of cold water, m_{cw}. Record the values of M_{c+cw} and m_{cw} in Table 1.

4. Measure and record the temperature of this water, T_{cw}, every 30 seconds until satisfied that measurements are consistent and reliable. Record its value in Table 1.

5. Fill a plastic beaker with ~ 100 ml of hot water. Stir this water very thoroughly and take its temperature, T_{hw}, with care. Record its value in Table 1.
6. Add this hot water to the cold water in the calorimeter. Stir the contents of the calorimeter gently, recording temperatures at 30-second intervals until satisfied that the final temperature, T, of the mixture is accurately known. Record its value in Table 1.

7. After obtaining the final temperature, again measure the total mass of the calorimeter cup and its contents, $M_{c+cw+hw}$, and determine the mass of hot water, m_{hw}. Record the values of $M_{c+cw+hw}$ and m_{hw} in Table 1.

Table 1

M_c (g)	M_{c+cw} (g)	m_{cw} (g)	T_{cw} (°C)	$M_{c+cw+hw}$ (g)	m_{hw} (g)	T_{hw} (°C)	T (°C)

8. Analyze the observed phenomenon in terms of conservation of energy using Eq. (3) given above and record the results in Table 2.

Table 2

$Q_{T\to T_{cw}}$ (J)	$\sigma_{Q_{T\to T_{cw}}}$ (J)	$Q_{T_{hw}\to T}$ (J)	$\sigma_{Q_{T_{hw}\to T}}$ (J)

Question 1. How closely do the calculations for both sides of the equation agree?

Compare this with your analysis of possible errors:

Question 2. What do your results indicate as to the constancy of the specific heat of water in the range of temperatures used in your procedure?

Experiment 2. Latent Heat of Fusion

The second experiment that you will perform will determine the latent heat of fusion for water. You will do this by adding ice at 0 °C to hot water. Masses should be obtained by weighing the calorimeter cup and contents (like in your previous activity). Use Table 3 to record your results of measurements and calculations.

9. Measure 100mL of hot water (between 70°C and 100°C), pour it into the calorimeter, and then measure its new temperature and mass.

10. Add bits of ice to the hot water. Use ice that is in equilibrium with water in an ice water supply provided.

11. Add ice until the last bit of melted ice brings the temperature down to about 10°C.

12. Carefully determine the final temperature by recording the temperature at 30-second intervals until satisfied that the final temperature, T, of the mixture is accurately known. To find the mass of the ice, m_{ice}, added to calorimeter, measure the final mass of water and calorimeter, $M_{c+hw+ice}$.

13. Use the equation below to determine the latent heat of fusion for water:

$$m_{ice}L_F + m_{ice}c_w(T - 0°C) = m_{hw}c_w(T_{hw} - T) \tag{4}$$

where m_{ice} = mass of the ice, and L_F = latent heat of fusion.

Table 3

M_c (g)	M_{c+hw} (g)	m_{hw} (g)	T_{hw} (°C)	$M_{c+hw+ice}$ (g)	m_{ice} (g)	T (°C)	L_F (J/g)

Question 3. What do the different terms of the Eq. (4) represent?

Question 4. What is the uncertainty, σ_{L_F}, in your value of L_F? Show your calculations of the σ_{L_F} below.

In the space provided below, record your experimental value of L_F in the following form: $L_F \pm \sigma_{L_F}$

$L_F =$ ________________ $\pm$ ________________ (J/g)