The Specific Heat of Aluminum Purpose

Goals:

1. To review the physical concepts and relationships associated with the flow of heat in and out of materials.
2. To apply the principle of conservation of energy in heat flow measurements
3. To determine the specific heat of aluminum (in the temperature range between boiling water and room temperature water).

Introduction

Heat is the energy associated with the thermally excited motion of atoms and molecules. When heat is transferred to a substance at constant pressure, its temperature usually rises. The exception to this rule occurs when there is a change of phase (e.g., a solid is changed into a liquid phase or a liquid state is changed into its vapor phase). A phase change occurs without increase or decrease in the substance's temperature.

If an object is isolated from the rest of the universe, no heat can flow into or out of that object. As a result, its temperature will remain unchanged. If it is brought into thermal contact with another object that is at a different temperature heat will flow out of the object that is hotter and into that which is cooler. The thermal energy of the hotter object will decrease and that of the cooler object will increase. Heat will continue to flow until the temperature of both objects is the same. At this point they are said to be in thermal equilibrium.

How is heat transfer quantified? The traditional unit of heat energy, the **calorie**, was defined as the amount of heat energy needed to raise the temperature of one gram of water by one degree Celsius. The calorie is now defined in terms of the SI unit of energy, the **joule**, by:

1 cal = 4.184 J

When heat flows into or out of an object, its temperature will change. The connection between the change in heat energy and the change in temperature is the **specific heat**. The heat energy, ΔQ, needed to raise the temperature, ΔT, of a substance is related to its mass m according to the formula:

$$\Delta Q = mc\Delta T = mc\left(T_f - T_i\right) \qquad (1)$$

The specific heat, c, is defined as the heat energy needed to raise the temperature of one gram of a substance by one degree Celsius (℃). In general, the value of the specific heat of a solid substance is dependent on the temperature, something we will revisit in the near future. Small variation of the specific heat also occurs due to variation in pressure or volume. The value of c in the above equation is taken as its average value, $\bar{c}$, over the temperature interval between its initial and final temperatures, T_i and T_f respectively.

The specific heat of substances varies with the temperature, as for example, the average value of the specific heat of aluminum is 0.17 cal/(g °C) between room temperature and liquid nitrogen temperature while it remains essentially constant (0.215 cal/(g °C)) from room temperature to 100 °C. In contrast to this, the specific heat of water decreases from 1.00728 cal/(g °C) to 0.99795 cal/(g °C) in the temperature range 0 to 35°C and then increases to 1.00697 cal/(g °C) at 100°C.

Determination of the Specific Heat of Aluminum at Temperatures from 100°C to 20°C

In this experiment, the specific heat of aluminum is measured by immersing an aluminum cube of known mass, m_{Al}, and initial temperature, $T_{i,Al}$, (around 100.0°C) into water of known mass, m_w, and initial temperature $T_{i,w}$, and measuring the final same equilibrium temperature, T_f. At thermal equilibrium, the cube and the water are at the same temperature. If there is no loss or gain of heat energy from or to the environment by the water or the aluminum cube (the cube and the water is an isolated system), the heat **lost** by the aluminum will be equal to the heat **gained** by the water. Conservation of energy, $\Delta Q_{Aluminum} + \Delta Q_{Water} = 0$, yields:

$$-\Delta Q_{Aluminum} = \Delta Q_{water} \qquad (2)$$

The minus sign indicates that heat is flowing out of the aluminum cube and into the water. Applying the principle of the conservation of energy, $-\Delta Q_{Aluminum} = \Delta Q_{Water}$, and using Eq. (1), one obtains the following equation applicable to this experiment:

$$-m_{Al}c_{Al}\left(T_{f,Al} - T_{i,Al}\right) = m_w c_w\left(T_f - T_i\right) \qquad (3)$$

Solving for the specific heat one obtains the experimental (*exp*) value:

$$c_{Al} = -\frac{m_w c_w\left(T_{f,w} - T_{i,w}\right)}{m_{Al}\left(T_{f,Al} - T_{i,Al}\right)} \qquad (4)$$

Experimental Apparatus and Procedure **Experimental Apparatus**

1. Celsius Thermometer
2. Aluminum Cube
3. Water
4. Small Double Styrofoam Cup for Water
5. Beaker
6. Hot Plate
7. Digital Thermometer
8. Double Pan Balance

Procedure
Measurement of the Average Specific Heat of Aluminum Between 100°C to 20°C.

1. Determine the mass, in grams, of the aluminum cube (m_{Al}). Example: 43.98 grams. Use two numbers after the decimal point. Be sure to place another paper clip on the right pan of the balance to "balance out" the paper clip attached to the cube. The mass of the thread is considered to be negligible. Repeat this measurement on four different scales to determine better values for the mass and precision in measuring mass.

2. Place water and the end of the digital thermometer cable into a glass beaker. Place the beaker on a hot plate and heat it. Initially, set the hot plate knob to high. Once the water is at a steady boil, note the temperature on the digital thermometer, and immerse the cube. The temperature will recede. Two groups may use the same hotplate. Be sure to keep track of your cube and the boiling time.

3. While the cube in the beaker is getting to the boiling point, weigh the smaller double Styrofoam cup. Fill it with room temperature tap water (approximately 60 to70 g) and record the mass. Compute the mass (m_w) of the water in the cup. Example: 60.44 grams. (Two decimal places is the correct precision for the mass balances used in this experiment)

4. When the boiling water returns to approximately the temperature noted in part 2 (before the cube was immersed) the cube should be close to (but not necessarily exactly equal to) 100.0°C. Let the cube boil for three minutes. It was important to note the temperature of the boiling water before cube was immersed. (The boiling point temperature changes with the atmospheric pressure and is also dependent on the purity of the water. In addition, there may be a small calibration error in the digital thermometer. We will assume a boiling temperature of 100.0°C and ignore this potential systematic error).

5. Measure the temperature of the room temperature water room in five different cups that are close together. This will allow us to calculate S_T, which will represent our precision in our single measurements of temperature in this and following experiments. Insert a thermometer into the cup containing the tap water, and measure its initial temperature of ($T_{i,w}$). Allow a few minutes for the thermometer to come to thermal equilibrium.

6. When the water in the beaker with the cube has been boiling vigorously for three minutes, and the temperature returns to approximately 100.0°C, record the initial temperature ($T_{i,Al}$) of the cube as 100.0°C. Again, we will assume that the temperature is 100.0°C as the digital thermometer may have a calibration error.

7. Quickly remove the cube and insert it into the cup with the tap water. **Be very careful not to splash water out of the cup**. This will result in a systematic error.

8. Begin stirring the water once the cube is submerged. Again, do not splash water out of the cup. Make sure the cup with the thermometer is not close to the hot plate. When the water and aluminum cube system reaches its highest temperature, measure and record the

final thermal equilibrium temperature (T_f) of the system. You should take a temperature reading every 30 seconds, as you continue to stir, in order to truly quantify the highest temperature reached. Make sure the bottom of the thermometer is close to the bottom of the cup, but not in contact with the aluminum cube.

Data

Record, in Microsoft Excel, the following data:

Mass of Aluminum cube

m_{Al}, (g)

Temperature of the room temperature water

T (℃)

Mass of the Styrofoam cup: ________________________

Mass of the Styrofoam cup plus water ________________________

Mass of water (m_w) ________________________

Initial temperature of Tap Water ($T_{i,w}$) ________________________

Initial temperature of Aluminum Cube ($T_{i,Al}$) ________________________

Final temperature of Water ($T_{f,w}$) ________________________

Final temperature of Aluminum Cube ($T_{f,Al}$) ________________________

Calculations and Analysis of the Data and Error for Lab Report

1) Using the 1D Stats macro calculate the average and associated error of your five mass values: $\bar{m}_{Al}, S_m, S_{\bar{m}_{Al}}$. Here, note we will leave the subscript "Al" off S_m. Since this value was determined using multiple mass balances we will treat this as a measure of the uncertainty associated with any future single measurement made with this set of mass balances. Do the same for your five temperatures measurements, $\bar{T}, S_T, S_{\bar{T}}$.

2) Calculate $m_w = m_{c+w} - m_c$. **You should propagate your errors as you go.** These

are both single measurements of mass, so $S_{m_w} = \sqrt{(S_m)^2 + (S_m)^2} = \sqrt{2}S_m$.

3) Calculate. $\Delta T_w = T_f - T_{i,w}$. These two measurements were single measurements made with a thermometer, so $S_{\Delta T_w} = \sqrt{(S_T)^2 + (S_T)^2} = \sqrt{2}S_T$

4) Calculate $\Delta T_{Al} = -(T_f - T_{i,Al})$. Remember, Ti,Al is treated as a constant so $S_{\Delta T_{Al}} = S_T$.

5) Calculate the specific heat for aluminum in this temperature range, and its precision. The accepted value for the specific heat of aluminum in this temperature range is $\bar{c}_{Al,acc} = 0.215 \frac{cal}{g°C}$. Use the accepted value for the specific heat of water $\bar{c}_{w,acc} = 0.99823 \frac{cal}{g°C}$.

$$c_{Al,exp} = \frac{m_w c_w \Delta T_w}{\bar{m}_{Al} \Delta T_{Al}}$$

$$S_{c_{Al,exp}} = c_{Al,exp} \sqrt{\left(\frac{S_{m_w}}{m_w}\right)^2 + \left(\frac{S_{\Delta T_w}}{\Delta T_w}\right)^2 + \left(\frac{S_{\bar{m}_{Al}}}{\bar{m}_{Al}}\right)^2 + \left(\frac{S_{\Delta T_{Al}}}{\Delta T_{Al}}\right)^2}$$

$$\%diff = 100 * \left|\frac{c_{Al,exp} - \bar{c}_{Al,acc}}{\bar{c}_{Al,acc}}\right|$$

Here is a suggested Excel layout:

SUMSQ | =H3*SQRT((B11/B5)^2+(E12/E9)^2+(G6/G3)^2+(G12/G9)^2)

	A	B	C	D	E	F	G	H	I
1	m_{Al}	N	T	N	m_{cup}	$T_{i,w}$	ΔT_w	$\bar{c}_{Al,exp}$	$\bar{c}_{Al,acc}$
2	(g)	5	(°C)	5	(g)	(°C)	(°C)	(cal/(g*°C))	(cal/(g*°C))
3	####	$\bar{m}_{Al}$	####	$\bar{T}$	####	####	####	####	0.215
4	####	(g)	####	(°C)	m_{cup+w}	$T_{i,Al}$	$S_{\Delta Tw}$	$S_{\bar{c}Al,exp}$	$\bar{c}_w$
5	####	####	####	####	(g)	(°C)	(°C)	(cal/(g*°C))	(cal/(g*°C))
6	####	S_m	####	S_T	####	100	####	=H3*SQRT((B	0.99823
7	####	(g)	####	(°C)	m_w	T_f	ΔT_{Al}	% diff	
8		####		####	(g)	(°C)	(°C)	####	
9		$S_{\bar{m}Al}$		$S_{\bar{T}}$	####	####	####		
10		(g)		(°C)	S_{mw}		$S_{\Delta TAl}$		
11		####		####	(g)		(°C)		
12					####		####		

Questions

1. We have ignored the mass and specific heat of the thermometer. Does this make your measurement of the heat capacity of aluminum higher or lower?

2. What type of error would result if a digital thermometer was not properly calibrated? We ignored this error by using 100.0°C for boiling water. See the *Appendix on Measurement and Error* Analysis to help you to answer this question.

3. Would the final equilibrium temperature be higher or lower if 200.00 grams of tap water was used in this experiment? Explain.

4. How sensitive is your result to a systematic error in the digital thermometer or the mass balance? (If the initial temperature of your aluminum cube was 95°C , or if the mass balance was off by 5 grams, how would that affect your calculation?)
   a) Recalculate c_{Al} and percent difference using T_i=95°C.
   b) Recalculate c_{Al} and percent difference by first adding 5 grams to both m_w and $m_{Al.}$
   c) Which calculation changed the result more dramatically?