Thermal Physics

Purpose: To determine the specific heat of metal samples, and to determine the heat of fusion for ice.

Equipment: calorimeter, centigram balance, thermometer, DS interface, several metal samples, hot plates and water containers, tongs and ice.

Discussion: Part One, Specific Heat

As a form of energy, heat has the same units as work and energy, N • m or Joules. How much heat (Q) it takes to warm an object depends on several parameters: mass, temperature change (°C), phase change if any and the chemical composition of the materials. The amount of heat needed to warm a 1.0kg object by 1.0 °C is called its specific heat with MKS units of, Joules/(kg •°C). The quantity of heat lost or gained in a heat transfer is: **$Q = m\,c\,\Delta T$**

Copper has a specific heat of 387 J/kg •°C, so to heat up 500 g of copper from 23 °C to 35 °C would require:

$Q = m \cdot c \cdot \Delta T = (.5\text{kg}) \cdot (387\ \text{J/kg} \cdot {}^\circ\text{C}) \cdot (12.0\ {}^\circ\text{C}) = 2340$ J of heat.

The Law of heat exchange is a statement of the conservation of energy. In an insulated heat transfer process; the heat lost by the warmer objects is transferred to (gained by) the cooler ones. For today's laboratory exercise, this means:

Heat lost by sample + Heat gained by water + Heat gained by cup = 0
$(m \cdot c \cdot \Delta T)_{sample} = -[(m \cdot c \cdot \Delta T)_{water} + (m \cdot c \cdot \Delta T)_{cup}]$
(note: $\Delta T = T_f - T_i$ this means the ΔT for the sample will be negative; water and cup positive.)

Procedure:

1. Find the mass of the inner cup of the calorimeter.
2. Fill the cup about 1/4 full with water from the tap. Find the mass of the water and cup; then subtract he cup's mass to determine the mass of the water.
3. Assemble the inner cup into the outer cup, put the thermometer in the rubber stopper and into the plastic cover, making certain that its tip is immersed in the water. Using the DS interface, record the initial temperature of the water.
4. Using tongs, very quickly (to minimize heat loss) transfer one of the metal samples to the inner cup and cover quickly. Record the initial temperature of the sample. Read the thermometer to the nearest $.1^0$C. Occassionally, gently agitate the water in the calorimeter in a horizontal circular motion until the temperature no longer increases. Record this as the final temperature for all.
5. Measure the mass of the now-cool metal sample, and calculate its specific heat.
6. Repeat this process (steps 3-5) for a different type metal.
7. Compare your findings with the accepted values for the specific heat of the specimens listed below. Determine percent error.

Lead (Pb) 128 J/(kg • °C)	Tin (Sn) 210 J/(kg • °C)
Alum. (Al) 900 J/(kg • °C)	Zinc (Zn) 375 J/(kg • °C)
Copper (Cu) 387 J/(kg • °C)	Water 4186 J/(kg • °C)

DATA (Part 1)

Type of metal sample	________	________
Mass of cup (kg)	________	________
Mass of water (kg)	________	________
Initial temp. of water & cup (°C)	________	________
Initial temp. of metal sample (°C)	________	________
Final temp. of water, cup, & sample (°C)	________	________
Mass of sample (kg)	________	________
Change in temp. of cup (°C)	________	________
Change in temp. of water (°C)	________	________
Change in temp. of sample (°C)	________	________
Specific heat of sample (J/kg • °C)	________	________

CALCULATIONS: (Clearly show all eight numbers used, incl. UNITS!)

Results: specific heat of samples and relative % error.

Discussion: Part Two, Heat of Fusion

When any substance is changed from a solid to a liquid or from a liquid to a gas (or the reverse), then the substance undergoes a PHASE CHANGE, and a certain amount of heat per unit mass is transferred in order to make this change. For example, when a solid melts, this phase change takes place at the material’s melting point and the amount of heat absorbed by the solid per unit mass to cause this change is called the heat of fusion (L_f). it is the same amount of heat per unit mass that is lost by a liquid when, after being cooled to its freezing point, it solidifies. Similarly, if a material changes phase from a liquid to a gas, the amount of heat absorbed per unit mass is called the heat of vaporization (L_v), and the temperature at which this takes place is the boiling point of the material. Again, this heat of vaporization is also equal to the amount of heat lost by a gas when, after being cooled to its boiling point, it condenses. Heats of fusion/vaporization have units of joules per kilogram, or calories per gram:

Q (phase change) = $m \cdot L_f$ or $Q = m \cdot L_v$

In today's laboratory exercise, heat goes from the room-temperature water and cup into (a) warming the ice to 0 °C, (b) changing the phase of the ice at 0 °C to water at 0 °C, and finally (c) warming the "new water" from 0 °C to the final equilibrium temperature:
Heat lost by hot things = Heat gained by cold things,
OR:

Heat lost (cup) + Heat lost (water) = Heat gained (warm ice to 0 °C) + Heat gained (melt ice) + Heat gained (warm "new water")

$(m \cdot c \cdot \Delta T)$cup + $(m \cdot c \cdot \Delta T)$water = -[$(m \cdot c \cdot \Delta T)$warm ice + $(m \cdot Lf)$melt ice + $(m \cdot c \cdot \Delta T)$warm "new water"]

Knowing the masses of the water, cup, and ice used in this procedure, their temperature changes, and the specific heats for water, ice, and the cup, it is a simple algebraic exercise to determine the heat of fusion for ice. (13 of the 14 elements of the equation above are known).

Procedure:

1. Recall and record the mass of the inner cup.
2. Fill the cup at least 1/3 full of tap water. Determine and record the mass of the water and cup to find the mass of the water.
3. Assemble the inner cup and the insulation ring into the outer cup. Place thermometer in the rubber stopper and into the plastic lid, making sure that the thermometer tip will be immersed under water when the lid is in place. Record the initial temperature. Again, reading the thermometer accurately **TO THE NEAREST TENTH OF A DEGREE** is absolutely critical.

4. Using tongs, quickly transfer a specified amount of ice into the inner cup and cover. Gently agitate the calorimeter until all the ice is melted. When the temperature stops dropping, record this as the final temperature.
5. Determine and record the total mass of the cup, original water, and melted ice. Calculate the mass of "new water" (which equals the mass of the ice you put into the cup).
6. Calculate the heat of fusion for ice, and compare it to its accepted value of 335,000 J/kg, and compute % error.

DATA (Part 2)

Mass of cup ____________________ kg

Mass of water ____________________ kg

Mass of ice (reweigh after melting) ____________________ kg

Initial temp. of water and cup ____________________ °C

Initial temp. of ice ____________________ °C

Final equilib. temp. of all water & ice ____________________ °C

Change in temp. of water and cup ____________________ °C

Change in temp. of ice ____________________ °C

Change in temp. of "new water" ____________________ °C

CALCULATIONS: (Clearly show all numbers used, including UNITS!)

Result: Latent heat of fusion of water.

Questions: write questions and show all work and relative % error.

1. 50g or water at 20^0C is add to 70g of water at 40^0C. Use the law of heat exchange to find the final temp.

2. Determine the final temperature when 50g of ice at -10^0C is added to 200g of water at 30^0C. Use online resources to find the specific heat of ice. Show all steps in the heat exchange process.

3. A typical water heater holds 30 gallons or about 120kg of water. If the incoming 22^0C water is to be heated to 40^0C and electricity costs $.12/kWHr, how much will it cost to heat a full tank of water? (A kWHr is 3.6×10^6J)