Specific Heats and Latent Heats (about 2 hours) (8/15/12)

Introduction

Heat is energy transferred due to differences in temperature. Exactly how much the temperature changes due to heat transfer depends on the material in question. For example, it takes about three and a half times as much energy to change the temperature of a kilogram of iron as it does to change the temperature of a kilogram of lead by the same amount. The relationship between heat added (or removed), Q, and change in temperature, ΔT, is given by

$$Q = m\, c\, \Delta T,$$

where Q is the amount of heat, m is the mass, ΔT is the change in temperature and c is the *specific heat* of the material. In general the specific heat may change with temperature and will change as the phase (solid, liquid or gas) of the material changes.

In addition to the heat energy required to change temperature, heat energy is gained or lost when a material changes *phase*. The energy per unit mass required to change the nature of the bonding in a substance as it changes from solid to liquid or from liquid to gas is called the *latent heat,* and is given by

$$Q = L\, m,$$

where, again, Q is heat added or removed, m is mass and L is the latent heat. Latent heat for freezing/melting is called the latent heat of fusion, L_F, and latent heat for boiling/condensing is called the latent heat of vaporization, L_V.

Equipment

- metal beaker (for boiling)
- 5 Styrofoam cups (8oz.)
- metal specimens (5 of each)(share)
- specimen tongs
- balance
- beaker tongs
- beaker (250ml)
- pitcher (for water)
- hot plate
- 2 thermometers
- liquid nitrogen*(3 l)
- stop watch
- gloves
- eye protection
- paper towels

*(Note for instructor: Liquid nitrogen is normally available in either room 108 or 117. If not, try 311.)

<u>WARNING</u>: Liquid nitrogen will rise to dangerously high pressure if confined. Be sure liquid nitrogen is kept only in ventilated containers, or an explosion may occur, resulting in serious injury.

A. Mixing Warm and Cool Water (a "warm-up" exercise)

Determine the mass of 5 Styrofoam cups (i.e. stacked one inside the other). (Record your data in Table A.) Put about 100 grams of unheated water (i.e. 100ml since by definition 1 cubic centimeter (1/1000 liter) of water has a mass of 1g!) into the top cup and measure the mass of the cups plus the water. Measure the water temperature. Be sure to stir the water with the thermometer until you are sure the thermometer is in thermal equilibrium with the water. Place about 50ml of water into the 250ml beaker and heat it to about 45°C. Remove the beaker of warm water from the hot plate and measure the water temperature, then immediately pour the warm water into the cup with the unheated water. Stir thoroughly and measure the final temperature. Record the total mass of the cups with the mixed water.

Write up a description of your procedure and record the masses and temperatures of the unheated, heated, and mixed water samples in a data table. Does the final temperature you measured seem reasonable? Explain, using the word “heat” in your explanation.

Would you necessarily expect the same result if you mixed water with, for example, alcohol? Explain why or why not.

Set up an equation using $Q = m\ c\ \Delta T$ to express the hypothesis that the heat gained by the cool water during mixing is equal to the heat lost by the warm water. Solve this equation for the final temperature of the mixture and substitute the measured values for the initial temperatures of the warm and cool water, and calculate the expected final temperature of the mixture. How does your calculated result compare to your measurement of the final temperature?

B. Hot Metal in Cool Water: Specific Heats

Fill a 250 ml beaker about half full of water, pour the water into the metal beaker, place it on a hot plate and begin heating it. Turn the hot plate knob to the highest setting. **CAUTION: Be careful handling hot beakers, water, metals or hot plate surfaces. <u>Gloves and safety goggles are available for your protection</u>.**

While waiting for the water to boil, measure and record the total mass of 5 specimens of the metal you are using (in Table B), then carefully place them in the water being heated using specimen tongs. (They should be covered by the water.)

Empty out the 5-cup "calorimeter" and fill it half full with room temperature water. Measure and record the total mass of the cups plus the water and the temperature of the “room temperature” water in Table B.

Leave the metal specimens in the hot water for at least 5 minutes after boiling has begun so you can assume that the temperature of the metal specimens is the same as the temperature of the boiling water. Using the specimen tongs, <u>carefully</u> remove each metal specimen from the boiling water and quickly lower it into the room temperature water in the Styrofoam cup. (All specimens should be covered with water.)

Gently stir the water in the Styrofoam cups for several minutes, frequently checking your thermometer for its highest reading. When the thermometer reading starts to fall, record the highest temperature reached in Table B as the final temperature of the system.

Write a paragraph explaining your procedure and discussing your data.

Repeat steps 1 through 7 for a set of 5 specimens of another metal, recording your information in the data table. Explain qualitatively what is happening to account for the final temperature.

Assume the heat gained by the water equals the heat lost by the specimen. The specific heat of water is 4186 J/(kg$\cdot{}^{0}$C). Explaining your work in full, calculate the specific heats of aluminum and copper. Compare to known values by finding a percent difference. Record the results in a table and discuss reasons for discrepancies.

C. Latent Heat of Vaporization of Liquid Nitrogen

<u>*CAUTION:LIQUID NITROGEN IS EXTEMELY COLD AND CAN CAUSE DAMAGE TO EYES:* ***EYE PROTECTION RECOMMENDED.*** *IT CAN ALSO CAUSE FROSTBITE ON SKIN.*</u>

<u>The rate of evaporation of liquid nitrogen</u>

Place one Styrofoam cup inside another and measure the precise mass of the two empty cups. With the cups still on the balance, set your balance 130 grams above the mass of the empty cups and carefully pour just enough liquid nitrogen into the cup to slightly exceed the setting. As the liquid nitrogen evaporates, the mass on the balance will decrease and momentarily become equal to the setting. At that instant, start your stopwatch, set your balance for 10 grams lower and wait until the balance arm swings back down. Stop your stopwatch as the pointer reaches the equilibrium point.

Record the time for 10 grams to evaporate here: _________.

Calculate the rate of evaporation of the liquid nitrogen (i.e. grams per second boiled away). Record this as Rate of Evaporation = _________ grams/sec.

(Note: Since the liquid nitrogen will be boiling, the temperature inside the liquid will be at the boiling point of liquid nitrogen at atmospheric pressure: 77 K.)

The Latent heat of vaporization of liquid nitrogen

Make two double-cup containers and label them "A" and "B". Carefully measure the mass of each container. Record them as mass of A and mass of B.

Pour 100 grams of warm (~50 °C) water into cup "A". Measure the mass and the temperature of the water. **REMOVE THE THERMOMETER.** Record Mass of Water and Initial Temp. of Water.

Pour about 40 grams of liquid nitrogen into cup "B". Quickly (to minimize loss due to evaporation) measure the mass of cup B (containing liquid nitrogen) and then pour the liquid nitrogen into cup A with the warm water. A white cloud of nitrogen vapor will show that the liquid nitrogen is boiling away. *Measure the time to evaporate all the nitrogen*. Record Mass of Nitrogen (not including cup) and Time to Evaporate.

When all the nitrogen is gone, gently stir the water until all the ice has melted. Measure the temperature of the water. Record as Final Water Temperature.

Determine how much nitrogen would have evaporated in the same time even without the water. (Use your rate from the previous part.) Subtract that from the initial mass of nitrogen to find out how much evaporated due to the water only.

Assume that the heat released as the water cooled went into boiling the nitrogen. Determine the Latent heat of vaporization for nitrogen.

Write out a description of your procedure and record your data in a data table.

Describe your calculations in full, including a verbal description of what is happening. Compare to the accepted value for L_V of nitrogen. The results may not be precise, since this experiment is not sufficiently isolated from the room, but you should be able to determine the order of magnitude of the latent heat of vaporization of nitrogen.

Table 1

Material (Room Temp)	Specific Heat c, $Joules/kg \cdot {}^0$C
Aluminum	900
Brass	380
Copper	387
Iron (or steel)	448
Lead	128
Glass	837
Water (15 ^{0}C)	4186
Ice (-5 ^{0}C)	2090

Table 2

Material	**Melting Temp ^{0}C**	**L_F J/kg**	**Boiling Temp ^{0}C**	**L_V J/kg**
Nitrogen	-209.65	2.55×10^4	-195.81	2.01×10^5
Water	0.00	3.33×10^5	100.00	2.26×10^6
Ethyl Alcohol	-114	1.04×10^5	78	8.54×10^5

A. Mixing Warm and Cool Water:
Procedure:

Volume of Cool Water	Mass of Cool Water	Temp. Cool Water	Volume of Warm Water	Mass of Warm Water	Temp Warm Water	Final Temp. of Mixture

Discussion:

B. Hot Metal in Cool Water
Procedure:

Material	Mass of specimen	Temp. of specimen	Mass of Water	Initial Temp. of Water	Final Temp.	Specific Heat	% Diff.

<u>Discussion and Calculations (Add a separate page if needed.)</u>

C. Liquid Nitrogen
Evaporation of liquid nitrogen
Procedure:

Time = ____________________ for 10 grams to boil away.

Rate of Evaporation = ________________ grams/sec

Latent heat of vaporization
Procedure:

Mass Water	Initial Temp Water	Final Temp Water	Heat Lost by Water	
Initial Mass Nitrogen	Time to Evaporate	Amount that would have Evaporated by itself	Mass Evaporated by Water	Heat added to Nitrogen by Water
Latent Heat of Nitrogen		Accepted Value		% Difference

Discussion and Calculations: (Add a separate page if needed.)