Calorimetry and Latent heat

Purpose

1. To study heat transfer associated with mixing a hot object with a cooler object.

2. To study change of state of matter and latent heat, L.

Introduction

As mentioned in the previous experiment, heat flows from a hot object to a colder object. If a hot liquid is at a temperature T_h and a colder liquid is at a temperature T_c, are mixed, then heat flows from the hot liquid to the colder liquid, until the temperature of the mixture stabilizes at T_f. By conservation of energy, the quantity of heat lost by the initially hot liquid is equal to the quantity of heat gained by the initially colder liquid.

$$Q_{h\ lost} = Q_{h\ gained} \qquad (1)$$

or using eqn. (3) of last experiment:

$$m_1 c_1 \Delta T_1 = m_2 c_2 \Delta T_2 \qquad (2)$$

ΔT_1 is the positive value of the change in temperature of the initially hot liquid, and ΔT_2 is the change in temperature of the initially colder liquid, So

$$\Delta T_1 = T_h - T_f \qquad \text{and} \qquad \Delta T_2 = T_f - T_c \qquad (3)$$

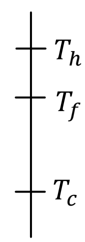

Figure 1: Temperature diagram

Calorimetry is the study of changes associated with transfer of heat. It is useful to represent the temperatures as shown in figure 1. The mixture could be made by any two objects. For example, a solid block inserted into water, still follows the same equation, eqn. (2), for heat lost equals heat gained.

Latent heat:

As mentioned in the previous experiment, the heat gained by an object goes into increasing the internal energy of the object. The internal energy of the object is the sum of the kinetic and the potential energy of its molecules. The potential energy of the molecules is lower when the molecules are tightly bound to each other. Taking, again the example of a solid, as heat flows into the solid, the vibration of its molecules increase, thus the vibration kinetic energy of the molecules increase. Temperature is a measure of the average kinetic energy of the molecules, so temperature increase. As heat continues to flow into the solid temperature continues to increase, up to the point where the vibration of the molecules reaches a maximum. After that the vibration kinetic energy cannot increase further, so any extra heat added will go into increasing the potential energy of the molecules. As mentioned above the potential energy is lower for molecules that are tightly bound to each other. Increasing the potential energy of the molecules, by adding heat, goes into decreasing the binding between the molecules. Therefore, the heat added goes into breaking the intermolecular bindings and the solid starts to melt. Remember that temperature is a measure of the average kinetic energy of the molecules. Since the melting of the solid, is due to increasing the potential energy of its molecules, not the kinetic energy of the molecules, then the change of state from solid to liquid occurs at a constant temperature. Indeed ice melts to water at a constant temperature of 0^oC. The same argument holds for boiling (evaporation) of a liquid. The Quantity of heat, Q_h, needed for changing the state of an object is proportional to the mass of the object:

$$Q_h \ \alpha \ m \qquad (4)$$

The constant of proportionality is called, the latent heat, L depends on the type of material of the object:

$$Q_h = m\,L \qquad (5)$$

The latent heat for melting, L is defined as the quantity of heat needed to melt one kg of the object. Similarly the latent heat for evaporation (or boiling) is defined as the quantity of heat need to evaporate one kg of the object.

If we start with an initial mass of water, m_1 at temperature T_h and an initial mass of ice , m_2 at temperature T_c and we mix them. The heat lost by the water: $m_1 c_w \Delta T$, will go partly into increasing the temperature of the ice from T_c to $0^o C$, then the remaining amount of heat lost by the water will go into melting a certain mass of the ice. The mass of ice that will melt depends on how much energy is left over after raising the temperature of the whole mass of ice, m_2 from T_c to $0^o C$. By conservation of energy $Q_{h\ lost} = Q_{h\ gained}$:

$$m_1 c_w \Delta T = m_2 c_{ice} \Delta T + m_{melted\ ice} L \qquad (6)$$

Where L is the latent heat of *fusion* or *melting* for ice.

Part 1: Using Calorimetry to find the final temperature, T_f of a mixture, and to find the value of an unknown specific heat, c **(The data sheet is on page 3)**

1) Assume we have a hot block of solid object of mass $m_1 = 2\ kg$, and specific heat $c_1 = 390\ J/kg.K$, at temperature $T_h = 700\ K$, and a beaker of water (c_2= 4186 J/ kg. K), at a temperature of $T_c = 300\ K$ and the mass of water, $m_2 = 10\ kg$. Using equation (2), calculate the final temperature, T_f reached when the block is inserted into the water.

2) Now open the simulator: https://www.compadre.org/Physlets/thermodynamics/ex19_3.cfm

Read the explanatory text. Keep all default values. Play the simulator until the animation ends, and the final temperature, T_f of the mixture is displayed. Compare to your calculated, T_f of step 1.

3) Click Reset. Change the mass of the block, m_1 to 3 kg, and repeat steps 1 and 2.

4) Now assume we do not know the specific heat c_1 of the solid block. Using equation (2), use the mass, m_1 and final temperature, T_f of step 3, to calculate the specific heat of the block (m_2 of the water is the same). Compare to the given value, $c_1 = 390\ J/kg.K$.

Part 2: An example involving change of state

1) Assume we have an initial mass of water, $m_1 = 100\ g$ at a temperature of $T_h = 10^o C$, and an initial mas of ice, $m_2 = 100\ g$ at $T_c = -10^o C$. If we mix them, use equation (6) to find the mass of ice that will melt.

2) Open the simulator http://physics.bu.edu/~duffy/HTML5/ice_and_water.html Read the explanatory text. Notice, in the explanatory text, the values used by the simulator for the specific heat of water, the specific heat of ice, and the latent heat of fusion of ice. Compare the value of melted ice to your calculated value.

3) If the initial mass of the water is $200\ g$, using equation (6), calculate the amount of ice expected to melt.

4) Now let try step 3 using the simulator. Set the initial mass m_1 of the water to $200\ g$ and notice the mass of ice and water **after** mixing as given by the simulator. Compare you calculated value (of step 3) for the mass of melted ice to that given by the simulator.

5) Now assume we do not know the latent heat of fusion of ice, L. Using the values of steps 1 and 2 for m_1 and m_2 and $m_{melted\ ice}$, and using equation (6) calculate L and compare to the value of $80\ cal/g^o C$ (this is an approximated value).

Questions

1. 50 grams of water at an initial temperature of 54°C and 110 grams of water at an initial temperature of 20°C are mixed. What is the final temperature? (The specific heat of water, $c_{liquid\ water} = 1\ cal/g^oC$).

2. How much heat must be added to 900 grams of water at 100°C to make it steam at 100°C? (The latent heat for vaporization of water is 539 cal /g).

Data Sheet

Name: **Group:** **Date experiment performed:**

Part 1: Using Calorimetry to find the final temperature, T_f of a mixture, and to find the value of an unknown specific heat, c

Show all your work for calculations

Step 1) $m_1 = 2\ kg$. Calculation of T_f:

Step 2) T_f as measured by the simulator:

Step 3) $m_1 = 3\ kg$. Calculation of T_f:

Compare toT_f as measured by the simulator:

Step 4) Calculation of the specific heat of the blue block, c_1:

Part 2: An example involving change of state

Show all your work for calculations

Step 1) $m_1 = 100\ g$. Calculation of $m_{melted\ ice}$:

Step 2) Compare to value measured by the simulator:

Step 3) $m_1 = 200\ g$. Calculation of $m_{melted\ ice}$:

Step 4) Compare to value measured by the simulator:

Step 5) Calculation of L, the latent heat of fusion of ice:

Answers to questions:

1.

2.