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CONSERVATION OF THERMAL ENERGY

INTRODUCTION

We will examine the exchange of heat between two samples of the same substance which are initially at different temperatures, and also the heat transfer associated with changes of state, i.e. melting, evaporation, and sublimation.

EXPERIMENTAL PROCEDURE

Reminder: The temperature probes associated with the computerized data acquisition system are designed for temperatures up to 80°C. If you wish to measure higher temperatures, you will need to use a mercury thermometer. Use care not to break the mercury thermometers. Should a mercury thermometer break, however, please notify your instructor immediately.

In carrying out some or all of the suggested procedures, be careful to avoid injuries through contact with hot or cold objects or substances.

Thermal energy conservation

The specific heat of liquid water at atmospheric pressure is very nearly constant between 0°C and 100°C. If we mix two masses of water at different initial temperatures T_1 and T_2 in a calorimeter, and the mixture comes to an equilibrium temperature T_0 , we can test whether energy is conserved by checking the validity of the relationship

$$M_1 C_1 (T_0 - T_1) = M_2 C_2 (T_2 - T_0), \dots \dots \dots (6.1)$$

where cal/g-°C. Weigh an insulation cup or beaker, and then fill it about 1/3 full of cold water, weigh it, and carefully measure its temperature. Fill a second cup about 1/3 full of boiling (or extremely hot) water, measure its temperature, and then carefully pour it into the cold water cup. Stir gently, and record the temperature of the mixture when it stabilizes. Then weigh the cup and water again to determine the mass of the hot water. Is Equation (6.1) consistent with your measurements?

Heat of fusion of water

Take about 3/4 cup of fairly warm water and determine its mass and temperature. Dry a piece of ice provided by your instructor, and gently slip it into the water. Stir gently until the ice has melted and record the thermal equilibrium temperature finally reached. Weigh the cup again to determine the ice mass. Determine the heat of fusion of ice from your data, and compare your result with the "standard" value. Note that the ice gains thermal energy first by melting and then by a rise in temperature to the final equilibrium temperature.

Heat of vaporization of water

Weigh a Pyrex beaker before and after partially filling it with water. Gently heat the water over a constant Bunsen burner flame or on a preheated hot plate. Monitor the temperature of the water as a function of time in order to determine the rate of heat energy transfer to the water. There is an optimum rate of heating: Too fast a rate will result in low accuracy in the determination of the time interval between two temperatures and will limit the number of time-temperature pairs which can be determined; too slow a rate will result in greater heat losses to the surroundings,

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which may be temperature-dependent. If you record a number of time-temperature pairs you will be able to get an estimate of the accuracy of your heating rate value as well as an indication of any increase in the rate of heat loss to the surroundings with increasing temperature of the water and beaker. (The latter can also be tested in a follow-up experiment by recording time-temperature pairs as a known mass of water in the beaker cools down after removing the heat source. Note, however, that this is not entirely straight-forward. If we simply turn off the gas or electricity, the stand used with a Bunsen burner or the hot plate will continue to supply heat to the water for a while, and may increase the rate of heat loss from the water after they have cooled down.)

Now knowing the net rate of supplying heat to the water (at least approximately), continue heating under constant conditions until the water starts to boil, and observe the time elapsed from the onset of boiling until a significant amount of water has evaporated. Remove the beaker from the heat supply, and determine the mass of water which has been evaporated by weighing the beaker and the remaining water.

Heat of sublimation of carbon dioxide

Determine the mass and temperature of some heated water in an insulation cup. Determine the mass of a sample of dry ice (solid carbon dioxide) placed in a cup. First weigh the empty cup, then (using tongs) place some dry ice in the cup and wait until the initial rapid sublimation stops as the bottom of the cup cools to near the temperature of dry ice. Now weigh the cup and dry ice, and as quickly as possible (but without splashing) drop the dry ice into the water. Stir the water with the thermometer and record the temperature as soon as possible after all the dry ice has vaporized. Your data should allow you to determine the heat of sublimation of carbon dioxide. You may have to repeat the procedure once or twice in order to optimize the relative amounts of water and dry ice or the initial water temperature for greater accuracy. Estimate the uncertainty in your result and whether your result is more likely to be too high or too low.

Conservation of Thermal Energy

Thermal energy conservation

M_1	M_2	T_1	T_2	T_0	$M_1 (T_0 - T_1)$	$M_2 (T_2 - T_0)$
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____

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_____	_____	_____	_____	_____	_____	_____
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Do your entries in the last two columns agree with each other?

Does the heat loss or gain by the calorimeter account for any observed discrepancies?

Heat of fusion of water

Mass of:

Beaker: _____ Beaker + Water: _____ Water (M_w): _____

Water Temperature: Initial (T_1): _____ Final (T_2): _____

Mass of:

Water + Beaker + Melted Ice: _____ Melted Ice (M_i): _____

Heat of Fusion = $[M_w(T_1 - T_2) - M_i(T_2 - 0)] / M_i =$ _____

How well does your result agree with the reference value of 80 cal/g?

Heat of vaporization of water

Initial mass of:

Beaker: _____ Beaker + Water: _____ Water (M_w): _____

Time	Temperature
_____	_____
_____	_____
_____	_____
_____	_____

Draw a graph of temperature vs. time. The slope is the rate of temperature change,

$DT / Dt =$ _____

The rate of heat transfer to water is

$DQ / Dt = M_w \times (1 \text{ cal/g } ^\circ\text{C}) \times (DT / Dt) =$ _____

Boiling from time $t_1 =$ _____ to time $t_2 =$ _____

Final mass of:

Beaker: _____ Water + Beaker: _____ Water (M'_w): _____

Mass of evaporated water ($M_w - M'_w$): _____

Heat of vaporization = $[(DQ / Dt) (t_2 - t_1)] / (M_w - M'_w) =$ _____

Heat of sublimation of carbon dioxide

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Initial water temperature $T_1 =$ _____

Mass of:

Beaker: _____ Beaker + Water: _____ Water (M_w): _____

Mass of:

Beaker: _____ Beaker + Dry Ice: _____ Dry Ice (M_i):

Final water temperature $T_2 =$ _____

Heat of sublimation = $(M_w / M_i) (1 \text{ cal/g } ^\circ\text{C}) (T_1 - T_2) =$ _____ cal/g $^\circ\text{C}$

How well does your result agree with the reference value of 137 cal/g?