CALORIMETRY: THE ENTHALPY OF FORMATION OF MgO

The experiment below is used with greatful acknowledgement of the United States Naval Academy

MATERIALS: 12 oz. Styrofoam cup with lid, thermometer, 100 mL graduated cylinder, weighing boat, 1.0 M HCl, 1.0 M NaOH, magnesium, magnesium oxide, copper wire, stir motor, stir bar.

PURPOSE: The purpose of this experiment is to determine the enthalpy of formation of magnesium oxide, i.e., \( \Delta H_f \) for the reaction:

\[
Mg (s) + \frac{1}{2} O_2 (g) \rightarrow MgO (s) \quad \Delta H_{rxn} = \Delta H_f (MgO)
\]

LEARNING OBJECTIVES: By the end of this experiment, the student should be able to demonstrate the following proficiencies:

1. Construct and use a calorimeter.
2. Determine the heat capacity of a calorimeter.
3. Calculate the enthalpy of a reaction from calorimetry data.
4. Apply Hess’s Law to calculate the enthalpy change associated with a reaction.
5. Use a spreadsheet program for data manipulation, graphing, and regression analysis.

DISCUSSION:
Elemental magnesium is one of the principal components of flares used to illuminate nighttime activities, or to aid in signaling one’s location to aircraft and ships. Your instructor may ignite a strip of magnesium ribbon to demonstrate the combustion of magnesium in air. It will be evident that a great deal of light energy is released from this reaction. A direct method for measuring the heat produced by this reaction would be extremely difficult, especially if it were to be carried out in pure oxygen as required for a bomb calorimetry experiment. Thus, we shall resort to an indirect method in this experiment as discussed below.

Some chemical reactions (including the one above) are associated with the evolution of thermal energy and are called exothermic reactions. When there is an absorption of energy in a chemical reaction, the process is called endothermic. The magnitude of the energy change is determined by the particular reaction as well as the amount of product(s) formed. The thermal energy transferred in a balanced chemical reaction carried out at constant pressure is called the enthalpy of reaction (or heat of reaction) and is given the symbol \( \Delta H_{rxn} \). \( \Delta H_{rxn} \) is often expressed in units of kJ/mole where mole refers to the amount of a reactant or a product involved in the reaction. In general, the reactant or product must be specified.

In this experiment, you will measure the enthalpy changes of several exothermic reactions utilizing a simple calorimeter. This calorimeter consists of an insulated vessel, a thermometer, and a lid (which is loose fitting to allow the pressure to remain constant). This constitutes an open system because the calorimeter is not truly isolated from its surroundings so matter and energy can be transferred between the system and the surroundings. A Styrofoam cup will be used as the insulated vessel in this experiment to help retain the heat. The energy given off by any reaction carried out in the calorimeter is absorbed by both the calorimeter and the solvent (water). This causes an increase in the temperature of the calorimeter and solvent that can be measured by a thermometer.

The heat, \( q \), that is absorbed by the calorimeter and solvent is calculated from the equation:

\[
q_{calorimeter} = C \cdot \Delta T \quad (1)
\]

where \( C \) is the heat capacity of the calorimeter and solvent, and \( \Delta T \) is the change in temperature of the water (the solvent) in the calorimeter. Heat capacity is defined as the amount of energy required to raise the temperature of an object by 1°C. In this experiment, the vessel and the amount of solvent remain constant, so \( C \) is a constant.

Enthalpy is an extensive quantity, so the amount of heat generated by the reaction is given by the expression:

\[
q_{reaction} = n \cdot \Delta H \quad (2)
\]
B. Determination of the Enthalpy of Formation of MgO

The calibrated calorimeter will be used to determine the enthalpy of formation of magnesium oxide by application of Hess’s law. Consider the following reactions:

(a) \( \text{H}_2 (g) + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{H}_2\text{O} (l) \) \( \Delta H_a = -285.84 \text{ kJ/mole} \)

(b) \( \text{Mg} (s) + 2 \text{H}^+ (aq) \rightarrow \text{Mg}^{2+} (aq) + \text{H}_2 (g) \) \( \Delta H_b \)

(c) \( \text{Mg}^{2+} (aq) + \text{H}_2\text{O} (l) \rightarrow \text{MgO} (s) + 2 \text{H}^- (aq) \) \( \Delta H_c \)

By adding equations (a), (b), and (c) we obtain

(d) \( \text{Mg} (s) + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{MgO} (s) \) \( \Delta H_{rxn} = \Delta H_f(MgO) = \Delta H_a + \Delta H_b + \Delta H_c \)

which represents the formation of MgO(s) from the elements in their standard states. By definition, the enthalpy change associated with equation (d) is the enthalpy of formation of MgO(s) and is symbolized by \( \Delta H_f(MgO) \).

Reaction (a) represents the formation of liquid water from its constituent elements. The enthalpy change for this reaction, symbolized \( \Delta H_a \) above, is the standard heat of formation of liquid water (or \( \Delta H_{fo} (\text{H}_2\text{O}) \)) and is a known quantity. \( \Delta H_b \) and \( \Delta H_c \) will be determined experimentally by measuring the temperature rise when known masses of magnesium metal and magnesium oxide, respectively, are added to hydrochloric acid. **Reaction (c) as written is an endothermic reaction. Since it is easier to perform the reverse (exothermic) reaction, the data you collect will be of opposite sign to that needed for the Hess’s law calculation for reaction (d).** By application of Hess’s law, the enthalpy of formation of magnesium oxide can be calculated by applying equation (d).
PROCEDURE:

Note: Handle the Styrofoam cups gently. They will be used by other lab sections! If your instructor demonstrates the combustion of Magnesium reaction, do NOT look directly at the burning Mg.

Part 1: Calibration of the temperature probe:
Use the Procedure from last week to calibrate the probe: use two containers of water
Water in the 15-20 degree range
Water in the 30-35 degree range

Part 2. Reaction of Magnesium Oxide and Hydrochloric Acid
Place 50.0 mL of 1.0 M HCl into a clean graduated cylinder.
On a top-loading balance, transfer approximately 0.4 to 0.5 g of MgO to a clean weighing boat (no need to record this mass). Next, determine the mass of the MgO and the weighing boat on the analytical balance and record the data. Transfer the MgO to the dry calorimeter.
On the analytical balance, record the mass of the “empty” weighing boat after the transfer and calculate the mass of MgO actually transferred to the calorimeter.
Record the initial temperature (Ti) of the 1.0 M HCl solution in the graduated cylinder.
Then add the 50.0 mL of 1.0 M HCl to the calorimeter containing the MgO. In this reaction all the MgO should react since HCl is used in excess. However, if the solid MgO is allowed to sit on the bottom or sides of the cup it will not dissolve and hence it will not react. Make sure the solution is mixing constantly but gently. Repeat this reaction 1 time (MgO plus HCl)

Part 3. Determination of the Enthalpy of Formation of Magnesium Oxide
1. Reaction of Magnesium and Hydrochloric Acid
Using a clean graduated cylinder, add 50.0 mL of 1.0 M HCl to the empty calorimeter.
Determine the mass of a sample of magnesium ribbon (about 0.15 g) on the analytical balance, then wrap it with a piece of copper wire. The copper will not react in the solution; its purpose is to prevent the magnesium from floating to the surface during the reaction. Do not wrap the magnesium too tightly with the copper or it will not react with the HCl solution. Do not wrap the magnesium too loosely since it may escape the copper “cage” and float.
Begin the run of the 1.0 M HCl in the calorimeter.
After 60 seconds, add the magnesium/copper bundle to the calorimeter. Stir the solution with the Mg/Cu bundle. Replace the thermometer and lid, and swirl the solution in a moderate and controlled fashion. Keep swirling the solution. After 300 plus seconds, look at the portion of the curve to make an extrapolation so make sure to collect enough data after the temperature starts decreasing. Repeat this reaction 1 time (Mg metal plus HCl)
When data collection is completed, rinse the calorimeter and thermometer with distilled water and dry as completely as possible. Place the piece of copper in the container labeled “copper waste.”
(Before discarding this solution, check to see that all of the MgO has reacted. If solid MgO remains, the results from this portion of the experiment are not accurate. If any solid is present, this portion of the experiment must be repeated.)

f. When data collection is completed, rinse the calorimeter and thermometer with distilled water and dry as completely as possible.

Clean up:
1. Wash all glassware. Rinse your calorimeter well and invert it on a paper towel to dry.
2. Return all equipment to their original location.