SKILL FOCUS

Performing and recording

Analyzing and interpreting

Communicating results

Investigation 5-B

# Hess's Law and the Enthalpy of Combustion of Magnesium

Magnesium ribbon burns in air in a highly exothermic combustion reaction. (See equation (1).) A very bright flame accompanies the production of magnesium oxide, as shown in the photograph below. It is impractical and dangerous to use a coffee-cup calorimeter to determine the enthalpy change for this reaction.

**(1)** $Mg_{(s)} + \frac{1}{2}O_{2(g)} \rightarrow MgO_{(s)}$

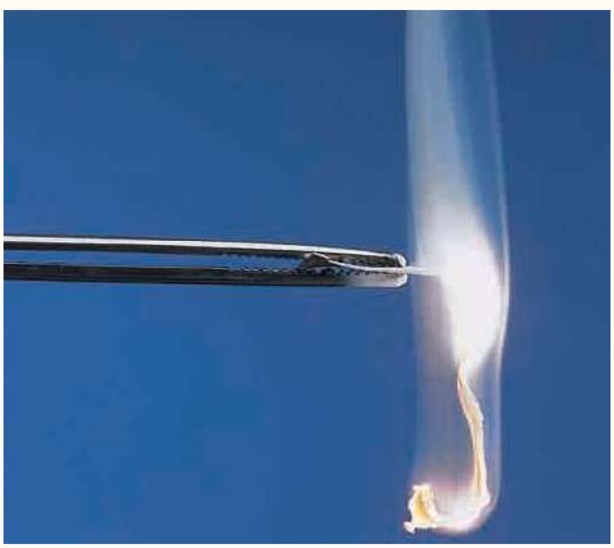
Instead, you will determine the enthalpy changes for two other reactions (equations (2) and (3) below). You will use these enthalpy changes, along with the known enthalpy change for another reaction (equation (4) below), to determine the enthalpy change for the combustion of magnesium.

**(2)** $MgO_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_2O_{(\ell)}$

**(3)** $Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$

**(4)** $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(\ell)}\ \Delta H^\circ = -285.8$ kJ/mol

Notice that equations (2) and (3) occur in aqueous solution. You can use a coffee-cup calorimeter to determine the enthalpy changes for these reactions. Equation (4) represents the formation of water directly from its elements in their standard state.



## Question

How can you use equations (2), (3), and (4) to determine the enthalpy change of equation (1)?

## Prediction

Predict whether reactions (2) and (3) will be exothermic or endothermic.

## Materials

coffee cup calorimeter (2 nested coffee cups sitting in a 250 mL beaker)
thermometer
100 mL graduated cylinder
scoopula
electronic balance
MgO powder
Mg ribbon (or Mg turnings)
sandpaper or emery paper
1.00 mol/L $HCl_{(aq)}$

## Safety Precautions

- Hydrochloric acid is corrosive. Use care when handling it.
- Be careful not to inhale the magnesium oxide powder.

## Procedure

**Part 1 Determining $\Delta H$ of Equation (2)**

1. Read the Procedure for Part 1. Prepare a fully-labelled set of axes to graph your temperature observations.
2. Set up the coffee-cup calorimeter. (Refer to Investigation 5-A) Using a graduated cylinder, add 100 mL of 1.00 mol/L $HCl_{(aq)}$ to the calorimeter. CAUTION $HCl_{(aq)}$ can burn your skin.

3. Record the initial temperature, $T_i$, of the $HCl_{(aq)}$, to the nearest tenth of a degree.
4. Find the mass of no more than 0.80 g of MgO. Record the exact mass.
5. Add the MgO powder to the calorimeter containing the $HCl_{(aq)}$. Swirl the solution gently, recording the temperature every 30 s until the highest temperature, $T_f$, is reached.
6. Dispose of the reaction solution as directed by your teacher.

**Part 2 Determining Δ*H* of Equation (3)**

1. Read the Procedure for Part 2. Prepare a fully-labelled set of axes to graph your temperature observations.
2. Using a graduated cylinder, add 100 mL of 1.00 mol/L $HCl_{(aq)}$ to the calorimeter.
3. Record the initial temperature, $T_i$, of the $HCl_{(aq)}$, to the nearest tenth of a degree.
4. If you are using magnesium ribbon (as opposed to turnings), sand the ribbon. Accurately determine the mass of no more than 0.50 g of magnesium. Record the exact mass.
5. Add the Mg to the calorimeter containing the $HCl_{(aq)}$. Swirl the solution gently, recording the temperature every 30 s until the highest temperature, $T_f$, is reached.
6. Dispose of the solution as directed by your teacher.

## Analysis

1. Use the equation $Q = m \cdot c \cdot \Delta T$ to determine the amount of heat that is released or absorbed by reactions (2) and (3). List any assumptions you make.
2. Convert the mass of MgO and Mg to moles. Calculate $\Delta H$ of each reaction in units of kJ/mol of MgO or Mg. Remember to put the proper sign (+ or –) in front of each $\Delta H$ value.
3. Algebraically combine equations (2), (3), and (4), and their corresponding $\Delta H$ values, to get equation (1) and $\Delta H$ of the combustion of magnesium.
4. **(a)** Your teacher will tell you the accepted value of $\Delta H$ of the combustion of magnesium. Based on the accepted value, calculate your percent error.
   **(b)** Suggest some sources of error in the investigation. In what ways could you improve the procedure?
5. What assumption did you make about the amount of heat that was lost to the calorimeter? Do you think that this is a fair assumption? Explain.
6. Why was it fair to assume that the hydrochloric acid solution has the same density and specific heat capacity as water?

## Conclusion

7. Explain how you used Hess's law of heat summation to determine $\Delta H$ of the combustion of magnesium. State the result you obtained for the thermochemical equation that corresponds to chemical equation (1).

## Extension

8. Design an investigation to verify Hess's law, using the following equations.

**(1)** $NaOH_{(s)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

**(2)** $NaOH_{(s)} + H^+_{(aq)} + Cl^-_{(aq)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)} + H_2O_{(\ell)}$

**(3)** $Na^+_{(aq)} + OH^-_{(aq)} + H^+_{(aq)} + Cl^-_{(aq)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)} + H_2O_{(\ell)}$

Assume that you have a coffee-cup calorimeter, solid NaOH, 1.00 mol/L $HCl_{(aq)}$, 1.00 mol/L $NaOH_{(aq)}$, and standard laboratory equipment. Write a step-by-step procedure for the investigation. Then outline a plan for analyzing your data. Be sure to include appropriate safety precautions. If time permits, obtain your teacher's approval and carry out the investigation.