

Determining the change in enthalpy for the combustion of Mg using solution calorimetry to validate Hess's law of heat summation.

Abstract *(AP only)*

Hess's law of heat summation states that the value of ΔH for a reaction is the same whether it occurs directly or as a series of steps. This principle was used to determine the change in enthalpy for a highly exothermic reaction, the combustion of magnesium metal. Enthalpy changes for the reactions of $\text{Mg}(s)$ in $\text{HCl}(aq)$ and $\text{MgO}(s)$ in $\text{HCl}(aq)$ were determined experimentally, then added to that for the combustion of hydrogen gas to arrive at a value of -616 kJ/mol Mg . Compared with the accepted value of -601.8 kJ/mol Mg , our experimental error was 2 %.

Introduction

In this investigation the change in enthalpy will be determined for the following equation: $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$, but in an indirect manner. Magnesium metal burns with a bright extremely hot flame to produce magnesium oxide. It would be difficult to measure the heat of the reaction since the reaction is rapid and occurs at a high temperature (LeMay et al, 1996). So, to determine the change in enthalpy we will employ Hess's Law of heat summation: It states that the value of ΔH for a reaction is the same whether it occurs directly or as a series of steps (Wilbraham et al, 2000).

We will perform the two following reactions: $\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$ and $\text{MgO} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2\text{O}$, determine their enthalpy changes (ΔH_s) experimentally, and they will

then be “added” to that of a given equation, the combustion of water, $\text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O}$ $\Delta H = -285.5 \text{ kJ/mol}$.

In this investigation we will be working with potentially dangerous chemicals and safety precautions must be taken. Magnesium oxide is a respiratory and eye irritant, the dust must not be inhaled and all work with MgO should be conducted in the fume hood. Hydrochloric acid (HCl) is extremely corrosive, inhalation of the vapor can cause serious injury, ingestion could be fatal, and the liquid can cause severe damage to the skin and eyes; when working with HCl splash goggles and gloves must be worn, and work should be conducted in a well ventilated area (Cartwright, 2002).

Materials and Methods

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|---|---------------------------------------|
| ◆ Goggles | ◆ Lab balance |
| ◆ Lab apron | ◆ 100mL graduated cylinder |
| ◆ Hydrochloric acid (HCl), 0.5 M | ◆ 2 plastic foam cups |
| ◆ Magnesium oxide MgO | ◆ thermometer |
| ◆ Magnesium (Mg) ribbon | ◆ cover for cup |
| ◆ 400mL beaker (transportation of acid) | ◆ 600mL beaker (base for calorimeter) |

We began this investigation by suiting up in lab aprons and goggles, we then gathered our materials, found a lab station and got to work. We decided to start with the magnesium in hydrochloric acid first, we measured out 198.5 mL of HCl and put it in the foam-cup calorimeter and took an initial temperature reading. We then selected a piece of magnesium ribbon and found its mass (see data table). This piece was placed in the calorimeter and the lid was shut immediately to prevent heat from escaping. We “swirled” the liquid mixture in the calorimeter to ensure reaction, and waited for a temperature change. After a few moments, the final temperature was recorded and ΔT determined. This process was then repeated.

We then moved onto the second reaction using magnesium oxide and hydrochloric acid in the fume hood. We measured 200.1 mL of HCl and placed it in the calorimeter, and initial temperature reading was taken. Next, we measured 1.07 g of magnesium oxide, using a balance in the fume hood, added it to the HCl in the calorimeter, and shut the lid quickly to conserve heat. This mixture was “swirled” and allowed a few moments to react. The final temperature was recorded and ΔT determined. This process was repeated successfully and the measurements can be seen below.

Results and Analysis

Throughout this investigation data was collected and placed in the tables below to be used in the calculations that follow.

Table 1: Results of Magnesium and Hydrochloric Acid

	Trial 1	Trial 2
Mass of Mg	0.04 g	0.05 g
volume of HCl	198.5 mL	199.4 mL
$T_{i \text{ HCl}}$	21.0 °C	20.9 °C
$T_{f \text{ Mg+HCl}}$	21.9 °C	22.0 °C
$\Delta T (T_f - T_i)$	0.9 °C	1.1 °C

Table 2: Results of Magnesium Oxide and Hydrochloric Acid

	Trial 1	Trial 2
Mass of MgO	1.07 g	1.04 g
Volume of HCl	200.1 mL	199.5 mL
$T_{i \text{ HCl}}$	21.5 °C	20.9 °C
$T_{f \text{ MgO+HCl}}$	25.8 °C	24.1 °C
$\Delta T (T_f - T_i)$	4.3 °C	3.2 °C

The enthalpy change for magnesium in hydrochloric acid was calculated from the experimental data (Table 1) in the following way. The average of two trials was used.



Trial 1:

$$0.04 \text{ g Mg} \times \frac{1 \text{ mol Mg}}{24.305 \text{ g Mg}} = 0.0016 \text{ mol Mg} \quad (198.5 \text{ mL} \times 1.00 \text{ g/mL} = 198.5 \text{ g})$$

$$q_{\text{sur}} = (198.5 \text{ g})(4.184)(0.9^\circ\text{C}) = 747 \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 0.747 \text{ kJ}$$

$$q_{\text{rxn}} = -0.747 \text{ kJ} \implies \Delta H = \frac{-0.747 \text{ kJ}}{0.0016 \text{ mol Mg}} = -400 \text{ kJ/mol Mg}$$

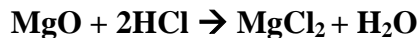
Trial 2:

$$0.05 \text{ g Mg} \times \frac{1 \text{ mol Mg}}{24.305 \text{ g Mg}} = 0.002 \text{ mol Mg} \quad (199.4 \text{ mL} \times 1.00 \text{ g/mL} = 199.4 \text{ g})$$

$$q_{\text{sur}} = (199.4 \text{ g})(4.184)(1.1^\circ\text{C}) = 918 \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 0.918 \text{ kJ}$$

$$q_{\text{rxn}} = -0.918 \text{ kJ} \implies \Delta H = \frac{-0.918 \text{ kJ}}{0.002 \text{ mol Mg}} = -500 \text{ kJ/mol Mg}$$

The enthalpy change for magnesium oxide in hydrochloric acid was calculated from the experimental data (Table 2) in the following way. The average of two trials was used.



Trial 1:

$$1.07 \text{ g MgO} \times \frac{1 \text{ mol MgO}}{40.304 \text{ g MgO}} = 0.0265 \text{ mol MgO} \quad (200.1 \text{ mL} \times 1.00 \text{ g/mL} = 200.1 \text{ g})$$

$$q_{\text{sur}} = (200.1 \text{ g})(4.184 \text{ J/g} \cdot ^\circ\text{C})(4.3 ^\circ\text{C}) = 3600 \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 3.600 \text{ kJ}$$

$$q_{\text{rxn}} = -3.600 \text{ kJ} \implies \Delta H = \frac{-3.600 \text{ kJ}}{0.0265 \text{ mol MgO}} = -140 \text{ kJ/mol MgO}$$

Trial 2:

$$1.04 \text{ g MgO} \times \frac{1 \text{ mol MgO}}{40.304 \text{ g MgO}} = 0.0258 \text{ mol MgO} \quad (199.5 \text{ mL} \times 1.00 \text{ g/mL} = 199.5 \text{ g})$$

$$q_{\text{sur}} = (199.5 \text{ g})(4.184 \text{ J/g} \cdot ^\circ\text{C})(3.2 ^\circ\text{C}) = 2670 \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 2.67 \text{ kJ}$$

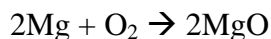
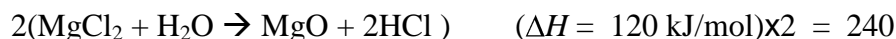
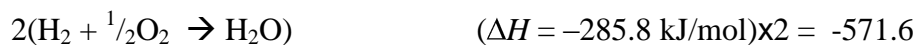
$$q_{\text{rxn}} = -2.67 \text{ kJ} \implies \Delta H = \frac{-2.67 \text{ kJ}}{0.0258 \text{ mol MgO}} = -1.0 \times 10^2 \text{ kJ/mol MgO}$$

The enthalpy change for the combustion of hydrogen gas was given and used in the final heat summation calculation.



$$\Delta H = -285.8 \text{ kJ/mol H}_2$$

The final heat summation calculation was performed in the following way.



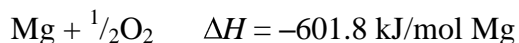
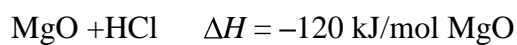
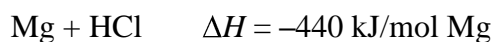
$$\Delta H = -1231 \text{ kJ/mol O}_2 =$$

$$\frac{-1231 \text{ kJ/mol O}_2}{2} = -616 \text{ kJ/mol Mg}$$

Discussion

After collection, analyses, and interpretation of the data it could be said that Hess's law was validated. Through the use of Hess's Law of heat summation, we were able to come reasonably close to the value for the change in enthalpy of burning magnesium from a series of other reactions. Though this process proved fairly successful in this investigation there was of course some error in our results compared to the accepted values provided by our instructor.

Using the following accepted values it was possible to calculate our percent error at different stages in the investigation as well as our final answer.



Percent error was calculated in the following way.

$$\text{Mg} + \text{HCl} \% \text{ error} = \frac{|-440 - (-450)|}{-440} \times 100 = 2 \%$$

$$\text{MgO} + \text{HCl} \% \text{ error} = \frac{|-120 - (-120)|}{-120} \times 100 = 0 \%$$

$$\text{Mg} + \text{O}_2 \% \text{ error} = \frac{|-601.8 - (-616)|}{-601.8} \times 100 = 2 \%$$

We found our change in enthalpy for magnesium in hydrochloric acid had a 2 % error, while our change in enthalpy for magnesium in hydrochloric acid had virtually a 0 % error. Our final answer was fairly accurate, having only a 2 % error. Any errors may be accounted for by not determining the heat capacity of the calorimeter before use. To avoid such error in the future one might determine the foam-cup calorimeter's heat capacity using hot water alone.

What is more, while care was taken to observe the rules governing the use of significant figures throughout our calculations, a balance capable of weighing to thousandths place (like the very expensive one used in AP Chemistry) might have been more practical in measuring the small amounts of magnesium ribbon used in this investigation.

Sources Cited

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(Additional sources are of course required for formal reports.)