

**AP<sup>®</sup> CHEMISTRY**  
**2013 SCORING GUIDELINES**

**Question 3**  
**(9 points)**



A student was assigned the task of determining the enthalpy change for the reaction between solid MgO and aqueous HCl represented by the net-ionic equation above. The student uses a polystyrene cup calorimeter and performs four trials. Data for each trial are shown in the table below.

Trial	Volume of 1.0 M HCl (mL)	Mass of MgO(s) Added (g)	Initial Temperature of Solution (°C)	Final Temperature of Solution (°C)
1	100.0	0.25	25.5	26.5
2	100.0	0.50	25.0	29.1
3	100.0	0.25	26.0	28.1
4	100.0	0.50	24.1	28.1

(a) Which is the limiting reactant in all four trials, HCl or MgO? Justify your answer.

$0.100 \text{ L} \times \frac{1.0 \text{ mol HCl}}{1.0 \text{ L}} = 0.10 \text{ mol HCl}$ $0.50 \text{ g MgO} \times \frac{1 \text{ mol MgO}}{40.30 \text{ g MgO}} = 0.0124 \text{ mol MgO}$ <p>By the stoichiometry of the equation, only <math>2 \times (0.0124 \text{ mol}) = 0.025 \text{ mol HCl}</math> is needed to react with the MgO, thus HCl is in excess and MgO is limiting.</p> <p>OR</p> <p>The temperature change depended on the amount of MgO added, indicating that MgO was the limiting reactant.</p>	<p>1 point is earned for the correct choice with justification.</p>
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(b) The data in one of the trials is inconsistent with the data in the other three trials. Identify the trial with inconsistent data and draw a line through the data from that trial in the table above. Explain how you identified the inconsistent data.

<p>Trial 1 is inconsistent.</p> <p>The temperature change should be directly proportional (approximately) to the amount of the limiting reactant present. The ratio <math>\Delta T / (\text{mass MgO})</math> should be constant. In trial 1, the ratio is one-half of trials 2, 3, and 4. Therefore, trial 1 is inconsistent with the other trials.</p>	<p>1 point is earned for identifying trial 1 with a valid justification.</p>
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**Question 3 (continued)**

For parts (c) and (d), use the data from one of the other three trials (i.e., not from the trial you identified in part (b) above). Assume the calorimeter has a negligible heat capacity and that the specific heat of the contents of the calorimeter is  $4.18 \text{ J}/(\text{g}\cdot\text{C}^\circ)$ . Assume that the density of the  $\text{HCl}(aq)$  is  $1.0 \text{ g/mL}$ .

- (c) Calculate the magnitude of  $q$ , the thermal energy change, when the  $\text{MgO}$  was added to the  $1.0 \text{ M}$   $\text{HCl}(aq)$ . Include units with your answer.

$q_{\text{calorimeter}} = q_{\text{cal}} = mc\Delta T$ <p>In trial 2, <math>q_{\text{cal}} = \left[ \left( 100.0 \text{ mL} \times \frac{1.0 \text{ g}}{\text{mL}} \right) + 0.50 \text{ g} \right] \left( \frac{4.18 \text{ J}}{\text{g}\cdot\text{C}^\circ} \right) (4.1^\circ\text{C}) = 1700 \text{ J or } 1.7 \text{ kJ}</math></p> <p>OR</p> <p>In trial 3, <math>q_{\text{cal}} = \left[ \left( 100.0 \text{ mL} \times \frac{1.0 \text{ g}}{\text{mL}} \right) + 0.25 \text{ g} \right] \left( \frac{4.18 \text{ J}}{\text{g}\cdot\text{C}^\circ} \right) (2.1^\circ\text{C}) = 880 \text{ J or } 0.88 \text{ kJ}</math></p> <p>OR</p> <p>In trial 4, <math>q_{\text{cal}} = \left[ \left( 100.0 \text{ mL} \times \frac{1.0 \text{ g}}{\text{mL}} \right) + 0.50 \text{ g} \right] \left( \frac{4.18 \text{ J}}{\text{g}\cdot\text{C}^\circ} \right) (4.0^\circ\text{C}) = 1700 \text{ J or } 1.7 \text{ kJ}</math></p>	<p>1 point is earned for the correct mass of the solution.</p> <p>1 point is earned for the correct calculation of <math>q</math> for any trial with a valid <math>\Delta T</math> and correct units.</p>
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- (d) Determine the student's experimental value of  $\Delta H^\circ$  for the reaction between  $\text{MgO}$  and  $\text{HCl}$  in units of  $\text{kJ/mol}_{\text{rxn}}$ .

<p>Assuming that no heat was lost to the surroundings, <math>q_{\text{rxn}} = -q_{\text{cal}}</math>.</p> <p>In trials 2 and 4,</p> $\Delta H^\circ = \frac{q_{\text{rxn}}}{n_{\text{MgO}}} = \frac{-1,700 \text{ J}}{0.50 \text{ g MgO} \times \frac{1 \text{ mol MgO}}{40.30 \text{ g MgO}}} = -140,000 \text{ J/mol}_{\text{rxn}} \times \frac{1 \text{ kJ}}{1000 \text{ J}}$ $= -140 \text{ kJ/mol}_{\text{rxn}}$ <p>In trial 3,</p> $\Delta H^\circ = \frac{-880 \text{ J}}{0.25 \text{ g MgO} \times \frac{1 \text{ mol MgO}}{40.30 \text{ g MgO}}} = -140,000 \text{ J/mol}_{\text{rxn}} \times \frac{1 \text{ kJ}}{1000 \text{ J}}$ $= -140 \text{ kJ/mol}_{\text{rxn}}$	<p>1 point is earned for the correct calculation of moles of <math>\text{MgO}</math> or setup of equation.</p> <p>1 point is earned for the value of <math>\Delta H^\circ</math> and sign consistent with the setup.</p>
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**Question 3 (continued)**

- (e) Enthalpies of formation for substances involved in the reaction are shown in the table below. Using the information in the table, determine the accepted value of  $\Delta H^\circ$  for the reaction between  $\text{MgO}(s)$  and  $\text{HCl}(aq)$ .

Substance	$\Delta H_f^\circ$ (kJ/mol)
$\text{MgO}(s)$	-602
$\text{H}_2\text{O}(l)$	-286
$\text{H}^+(aq)$	0
$\text{Mg}^{2+}(aq)$	-467

$\Delta H^\circ = \sum n_p \Delta H_f^\circ \text{ products} - \sum n_r \Delta H_f^\circ \text{ reactants}$ $= [\Delta H_f^\circ \text{Mg}^{2+}(aq) + \Delta H_f^\circ \text{H}_2\text{O}(l)] - [\Delta H_f^\circ \text{MgO}(s) + 2 \Delta H_f^\circ \text{H}^+(aq)]$ $= [-467 \text{ kJ/mol} + (-286 \text{ kJ/mol})] - [-602 \text{ kJ/mol} + 2(0) \text{ kJ/mol}]$ $= -151 \text{ kJ/mol}_{rxn}$	<p>1 point is earned for the correct setup using the <math>\Delta H_f^\circ</math> values.</p> <p>1 point is earned for the correct value and sign consistent with the setup.</p>
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- (f) The accepted value and the experimental value do not agree. If the calorimeter leaked heat energy to the environment, would it help account for the discrepancy between the values? Explain.

<p>Yes. The experimentally determined value for <math>\Delta H^\circ</math> was less negative than the accepted value. If heat had leaked out of the calorimeter, then the <math>\Delta T</math> of the contents would be less than expected, leading to a smaller calculated value for <math>q</math> and a less negative value for <math>\Delta H^\circ</math>.</p>	<p>1 point is earned for the correct response with a valid explanation.</p>
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