Your responses to the rest of the questions in this part of the examination will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

Answer BOTH Question 5 below AND Question 6 printed on page 11. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

5. A student is asked to determine the molar enthalpy of neutralization, ΔH_{neut}, for the reaction represented above. The student combines equal volumes of $1.0\,M$ HCl and $1.0\,M$ NaOH in an open polystyrene cup calorimeter. The heat released by the reaction is determined by using the equation $q = mc\Delta T$.

   Assume the following.

   - Both solutions are at the same temperature before they are combined.
   - The densities of all the solutions are the same as that of water.
   - Any heat lost to the calorimeter or to the air is negligible.
   - The specific heat capacity of the combined solutions is the same as that of water.

   (a) Give appropriate units for each of the terms in the equation $q = mc\Delta T$.

   (b) List the measurements that must be made in order to obtain the value of q.

   (c) Explain how to calculate each of the following.

   (i) The number of moles of water formed during the experiment

   (ii) The value of the molar enthalpy of neutralization, ΔH_{neut}, for the reaction between HCl(aq) and NaOH(aq)

   (d) The student repeats the experiment with the same equal volumes as before, but this time uses $2.0\,M$ HCl and $2.0\,M$ NaOH.

   (i) Indicate whether the value of q increases, decreases, or stays the same when compared to the first experiment. Justify your prediction.

   (ii) Indicate whether the value of the molar enthalpy of neutralization, ΔH_{neut}, increases, decreases, or stays the same when compared to the first experiment. Justify your prediction.

   (e) Suppose that a significant amount of heat were lost to the air during the experiment. What effect would this have on the calculated value of the molar enthalpy of neutralization, ΔH_{neut}? Justify your answer.

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Question 5

Total Score 10 Points

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

5. A student is asked to determine the molar enthalpy of neutralization, ΔH_{neut}, for the reaction represented above. The student combines equal volumes of 1.0 M HCl and 1.0 M NaOH in an open polystyrene cup calorimeter. The heat released by the reaction is determined by using the equation $q = mc\Delta T$.

   Assume the following.

   - Both solutions are at the same temperature before they are combined.
   - The densities of all the solutions are the same as that of water.
   - Any heat lost to the calorimeter or to the air is negligible.
   - The specific heat capacity of the combined solutions is the same as that of water.

   (a) Give appropriate units for each of the terms in the equation $q = mc\Delta T$.

q has units of joules (or kilojoules or calories or kilocalories) m has units of grams or kilograms c has units of J g^{-1} $°C^{-1}$ or J g^{-1} K^{-1} (calories or kilograms acceptable alternatives) T has units of °C or K	1 point earned for any two units 2 points earned for all four units

   (b) List the measurements that must be made in order to obtain the value of q.

• volume or mass of the HCl or NaOH <u>solutions</u> • initial temperature of HCl or NaOH before mixing • final (highest) temperature of solution after mixing	1 point earned for <u>any</u> volume (mass of reactant) 1 point earned for initial and final (highest) temperature (ΔT is <u>not</u> a measurement)

Question 5 (cont'd.)

(c) Explain how to calculate each of the following.

(i) The number of moles of water formed during the experiment

Since there is mixing of equal volumes of the same concentration and the reaction has 1:1 stoichiometry, moles of H_2O = moles of HCl = moles NaOH. To determine the number of moles of HCl: $(\text{volume HCl})\left(\frac{\text{mol HCl}}{1\text{ L}}\right)\left(\frac{1\text{ mol } H_2O}{1\text{ mol HCl}}\right) = \text{mol } H_2O$ **OR** $(\text{volume NaOH})\left(\frac{1.0\text{ mol NaOH}}{1\text{ L}}\right)\left(\frac{1\text{ mol } H_2O}{1\text{ mol NaOH}}\right) = \text{mol } H_2O$ **OR** $n_{H_2O} = n_{HCl} = n_{NaOH} = V_{HCl} \times 1\,M = V_{NaOH} \times 1\,M$	1 point earned for the number of moles of H_2O using the stoichiometric relationship between HCl (or NaOH) and H_2O

(ii) The value of the molar enthalpy of neutralization, ΔH_{neut}, for the reaction between HCl(aq) and NaOH(aq)

Determine the quantity of the heat produced, q, from $q = mc\Delta T$, where m = total mass of solution; divide q by mol H_2O determined in part (c) (i) to determine ΔH_{neut}: $\Delta H_{neut} = \frac{-q}{\text{mol } H_2O}$ **OR** $\frac{q}{\text{mol } H_2O}$ (mol reactant can substitute for mol H_2O)	1 point earned for q 1 point earned for ΔH_{neut}

Question 5 (cont'd.)

(d) The student repeats the experiment with the same equal volumes as before, but this time uses 2.0 *M* HCl and 2.0 *M* NaOH.

(i) Indicate whether the value of q increases, decreases, or stays the same when compared to the first experiment. Justify your prediction.

The ΔT will be greater, so q increases. There are more moles of HCl and NaOH reacting so the final temperature of the mixture will be higher.	1 point earned for direction and explanation

Note: Arguments about increased mass are not acceptable because the total mass increase is negligible (the solutions have virtually the same density) and is not the driving force for increases in q.

(ii) Indicate whether the value of the molar enthalpy of neutralization, ΔH_{neut}, increases, decreases, or stays the same when compared to the first experiment. Justify your prediction.

Both q and mol H_2O increase proportionately. However, when the quotient is determined, there is no change in ΔH_{neut} Molar enthalpy is defined as per mole of reaction, therefore it will not change when the number of moles is doubled.	1 point earned for correct direction and explanation

(e) Suppose that a significant amount of heat were lost to the air during the experiment. What effect would this have on the calculated value of the molar enthalpy of neutralization, ΔH_{neut}? Justify your answer.

Heat lost to the air will produce a smaller ΔT. In the equation $q = mc\Delta T$ a smaller ΔT will produce a smaller value for q (heat released) than it should. In the equation $$\Delta H_{neut} = \frac{-q}{\text{mol } H_2O}$$ the smaller magnitude of q and the constant mol H_2O means that ΔH_{neut} will be less negative (more positive).	1 point earned for correct direction and explanation

Notes: ΔH decreases because q decreases earns 1 point
ΔT decreases because ΔH decreases earns 1 point
No points earned for ΔT decreases therefore q decreases