AP® CHEMISTRY
2008 SCORING GUIDELINES

Question 2

Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

No additional mass was lost during the third heating, indicating that all the water of hydration had been driven off.	One point is earned for the correct explanation.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

mass of H_2O lost $= 25.825 - 23.977 = 1.848$ g *OR* $25.825 - 23.976 = 1.849$ g $1.848\text{ g } H_2O \times \frac{1\text{ mol } H_2O}{18.02\text{ g } H_2O} = 0.1026\text{ mol } H_2O$	One point is earned for calculating the correct number of moles of water.

(ii) determine the formula of the hydrated compound.

mass of anhydrous $MgCl_2 = 23.977 - 22.347 = 1.630$ g $1.630\text{ g } MgCl_2 \times \frac{1\text{ mol } MgCl_2}{95.20\text{ g } MgCl_2} = 0.01712\text{ mol } MgCl_2$ $\frac{0.1026\text{ mol } H_2O}{0.01712\text{ mol } MgCl_2} = 5.993 \approx 6\text{ mol } H_2O \text{ per mol } MgCl_2$ $\Rightarrow$ formula is $MgCl_2 \cdot 6H_2O$	One point is earned for calculating the correct number of moles of anhydrous $MgCl_2$. One point is earned for writing the correct formula (with supporting calculations).

Question 2 (continued)

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

The calculated mass (or moles) of water lost by the hydrate will be too large because the mass of the solid that was lost will be assumed to be water when it actually included some $MgCl_2$ as well.	One point is earned for the correct answer with justification.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the $AgCl$ precipitate.

Add excess $AgNO_3$. - Separate the AgCl precipitate (by filtration). - Wash the precipitate and dry the precipitate completely. - Determine the mass of AgCl by difference.	Two points are earned for <u>all three major steps</u>: filtering the mixture, drying the precipitate, and determining the mass by difference. One point is earned for any two steps.

(e) The student determines the mass of the $AgCl$ precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

$5.48 \text{ g AgCl} \times \frac{1 \text{ mol AgCl}}{143.32 \text{ g AgCl}} = 0.0382 \text{ mol AgCl}$ $0.0382 \text{ mol AgCl} \times \frac{1 \text{ mol Cl}}{1 \text{ mol AgCl}} \times \frac{1 \text{ mol } MgCl_2}{2 \text{ mol Cl}} = 0.0191 \text{ mol } MgCl_2$	One point is earned for calculating the number of moles of AgCl. One point is earned for conversion to moles of $MgCl_2$.

(ii) The percent by mass of $MgCl_2$ in the original mixture

$0.0191 \text{ mol } MgCl_2 \times \frac{95.20 \text{ g } MgCl_2}{1 \text{ mol } MgCl_2} = 1.82 \text{ g } MgCl_2$ $\frac{1.82 \text{ g } MgCl_2}{2.94 \text{ g sample}} \times 100\% = 61.9\% \text{ } MgCl_2 \text{ by mass}$	One point is earned for calculating the correct percentage.

2A1

2. Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

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Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

(ii) determine the formula of the hydrated compound.

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.

(e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

(ii) The percent by mass of $MgCl_2$ in the original mixture

ⓐ the mass of the sample did not change significantly between the second and third heatings

ⓑ initial mass of sample: 25.825g − 22.347g = 3.478g

mass of sample after heating: 23.977g − 22.347g = 1.630g

mass of water evaporated: 3.478g − 1.630g = 1.848g

i) molar mass of water = 18.02g/mol

$$1.848\text{g } H_2O \cdot \frac{1\text{mol } H_2O}{18.02\text{g } H_2O} = \boxed{.1026\text{mol } H_2O}$$

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2A2

(b) ii) molar mass of $MgCl_2$ = 95.20 g/mol

$$1.630\text{g } MgCl_2 \cdot \frac{1\text{mol } MgCl_2}{95.20\text{g } MgCl_2} = .01712\text{mol } MgCl_2$$

$$\frac{.1026\text{mol } H_2O}{.01712\text{mol } MgCl_2} = \frac{5.991\text{mol } H_2O}{\text{mol } MgCl_2}$$

$\therefore \boxed{MgCl_2 \cdot 6H_2O}$

(c) the calculated mass of water lost will be greater than the actual mass lost because the mass of whatever solid spattered will also be subtracted from the original sample

(d) • 2.94 g sample dissolved in water
• add excess $AgNO_3$ • ~~mass the empty filter~~
• once precipitate is formed, filter the solution
• pour through filter several times to be sure
• let the filter dry
• find the mass of filter and precipitate
• subtract mass of filter

(e) i) molar mass of AgCl = 143.42 g/mol

$$5.48\text{g AgCl} \cdot \frac{1\text{mol AgCl}}{143.42\text{g AgCl}} = .0382\text{mol AgCl}$$

$$\text{mol } Cl^- = \text{mol AgCl} = .0382\text{mol}$$

$$\text{mol } MgCl_2 = \tfrac{1}{2}\text{mol } Cl^- = \tfrac{1}{2}(.0382\text{mol}) = \boxed{.0191\text{mol } MgCl_2}$$

ii) $$.0191\text{mol } MgCl_2 \cdot \frac{95.20\text{g } MgCl_2}{1\text{mol } MgCl_2} = 1.82\text{g } MgCl_2$$

$$\frac{1.82\text{g } MgCl_2}{2.94\text{g}} \cdot 100\% = \boxed{61.9\%}$$

GO ON TO THE NEXT PAGE.

2. Answer the following questions relating to gravimetric analysis.

2B1

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

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(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

(ii) determine the formula of the hydrated compound.

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.

(e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

(ii) The percent by mass of $MgCl_2$ in the original mixture

A) The difference in mass of the container + sample gets smaller after each successive heating. The majority of the water was eliminated after the first heating (1.843 g worth), while the next heating lowered the mass by .006g + the following showed a slight increase.

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B) i) mass lost after heating 1 : 1.843 g

" heating 2 : .006 g

total mass lost : 1.849 g

$1.849\text{g } H_2O \cdot \frac{1 \text{ mol } H_2O}{18.016\text{g } H_2O} = \boxed{.1026 \text{ mol } H_2O}$

ii) mass sample : 25.825 g − 22.347 g = 3.478

less mass H_2O lost : 1.629 g = mass $MgCl_2$

$1.629\text{g } MgCl_2 \cdot \frac{1 \text{ mol } MgCl_2}{95.20\text{g } MgCl_2} = .01711 \text{ mol } MgCl_2$

$\frac{.1026 \text{ mol } H_2O}{.01711 \text{ mol } MgCl_2} = 5.996$, so there are ≈6 mol H_2O for each mol $MgCl_2$

$\boxed{\therefore \text{The formula is } MgCl_2 \cdot 6H_2O}$

C) As the solid spatters out, the sample will appear to have lost more water mass than it has Because the assumption is that the change in mass is due to water loss, students will conclude that the hydrate has lost more water.

D) Determine the mol Cl in the solution by calculating the ratio of moles $MgCl_2$ to KNO_3. Use this value to calculate the % of the mass $MgCl_2$ to KNO_3. From there, perform stoichiometry, determining first the moles $MgCl_2$ present + using this value to determine how many moles Cl_2 are present.

2B3

E) i) $5.48\ g\ AgCl : \frac{1\ mol\ AgCl}{143.32\ g\ AgCl} \cdot \frac{1\ mol\ MgCl_2}{2\ mol\ AgCl} = \boxed{.0191\ mol\ MgCl_2}$

ii) $.0191\ mol\ MgCl_2 \cdot \frac{95.02\ g\ MgCl_2}{1\ mol\ MgCl_2} = 1.81\ g\ MgCl_2$

$$\text{mass \%} = \frac{g\ MgCl_2}{g\ total} \cdot 100$$

$$= \frac{1.81\ g}{2.94\ g} \cdot 100$$

$$= \boxed{61.6\%\ MgCl_2}$$

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2. Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

2C,

Mass of empty container	22.347 g
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Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

(ii) determine the formula of the hydrated compound.

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.

(e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

(ii) The percent by mass of $MgCl_2$ in the original mixture

a) If the mass of the sample and container stops decreasing after the heating, the water has all been evaporated and what is left does not change mass with temperature increase.

b) i) (initial mass - container) − (mass after 3rd heating − container)
= (3.478) − (1.63) = 1.848 g H_2O lost

$1.848\,g\,H_2O \left(\frac{1\,mol\,H_2O}{18\,g\,H_2O}\right)$ = 0.103 moles of H_2O lost

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2C2

b) (ii) $3.478\text{ g } MgCl_2 \cdot nH_2O \left(\frac{1\text{ mol } MgCl_2 \cdot nH_2O}{(95.2 + n(18))\text{ g } MgCl_2 \cdot nH_2O}\right)\left(\frac{n\text{ mol } H_2O}{1\text{ mol } MgCl_2 \cdot nH_2O}\right) =$ 0.103 moles

$$\frac{3.478(n)}{95.2 + n(18)} = 0.103$$

$$3.478n = 9.774 + 1.848n$$

$$1.63n = 9.774$$

$$n = 5.996 \approx 6$$

$\boxed{MgCl_2 \cdot 6H_2O}$

c) Since some of the solid splattered out of the crucible, the mass of the water lost is now inflated to a much too great number. When the student sees that a certain mass has been lost from the heating, he or she will assume it is water that was lost. As a result, the mass of the water and therefore the moles of water in the formula too big.

d) $AgNO_3 + MgCl_2 \longrightarrow AgCl + MgNO_3$

(s) $Mg^{2+} + 2Cl^-$ (aq) (aq)

$AgNO_3 + 2Cl^- \longrightarrow AgCl + NO_3^-$

To determine the mass of AgCl precipitate, the amount of $AgNO_3$ added should first be known. Then the mixture of $MgCl_2$ and KNO_3 is added. The mass is then converted to moles through Cl ratios.

e) (i) $5.48\text{ g } AgCl \left(\frac{1\text{ mol } AgCl}{107.87 + 35.45\text{ g}}\right)\left(\frac{1\text{ mol Cl}}{1\text{ mol AgCl}}\right)\left(\frac{2\text{ mol Cl}}{1\text{ mol Cl}}\right)\left(\frac{1\text{ mol } MgCl_2}{1\text{ mol Cl}}\right) =$

(ii) $0.076\text{ moles } MgCl_2 \left(\frac{24.3 + 35.45 + 35.45\text{ g}}{1\text{ mol } MgCl_2}\right) = 7.28\text{ g } MgCl_2$

$\boxed{93.2\%}$

$\boxed{0.076\text{ moles } MgCl_2}$

AP® CHEMISTRY
2008 SCORING COMMENTARY

Question 2

Overview

This question assessed student knowledge and skills relating to gravimetric analysis, which is included in several of the laboratory experiments recommended in the *AP Chemistry Course Description*. In parts (a) through (c) students were asked to analyze and interpret a data table. They had to explain how they correctly determined that all the water of hydration had been driven off from a sample of a hydrate; calculate an appropriate formula for the hydrate; and determine the effect of an error in laboratory procedure on the calculation of the mass of water released upon heating. Parts (d) and (e) required students to describe a quantitative laboratory procedure to determine the mass of a precipitate from a mixture and then calculate the number of moles and percent by mass of a component of the mixture.

Sample: 2A
Score: 10

This response earned all 10 points: 1 for part (a), 1 for part (b)(i), 2 for part (b)(ii), 1 for part (c), 2 for part (d), 2 for part (e)(i), and 1 for part (e)(ii).

Sample: 2B
Score: 8

In part (d) no points were earned because the necessary steps were not described.

Sample: 2C
Score: 6

In part (d) no points were earned because the necessary steps were not described. In part (e)(i) 1 point was earned for dividing by the molar mass of AgCl, but the other point was not earned owing to the misapplication of the mole ratio in the calculation. In part (e)(ii) no point was earned. Although the answer brought down from part (e)(i) was multiplied by the correct molar mass, that product was not subsequently divided by 2.94 g, the mass of the original sample.