2022

AP® CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

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Free-Response Question 4

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Question 4: Short Answer — 4 points

(a) For a correct calculated value: **1 point**

$$1\text{ L} \times \frac{0.0016\text{ g}}{1\text{ L}} \times \frac{1\text{ mol}}{51.48\text{ g}} = 3.1 \times 10^{-5}\text{ mol}$$

(b) For the correct identification of intermolecular forces between each substance and water: **1 point**

Accept one of the following:

- *Both* NH_2Cl *and* NCl_3 *can participate in hydrogen bonding with water.*
- *Both* NH_2Cl *and* NCl_3 *have dipole-dipole attractions to water.*

For a correct explanation: **1 point**

The intermolecular forces between NH_2Cl *molecules and water are stronger than those between* NCl_3 *molecules and water, which leads to the greater solubility of* NH_2Cl *in water.*

Total for part (b) 2 points

(c) For the correct calculated value: **1 point**

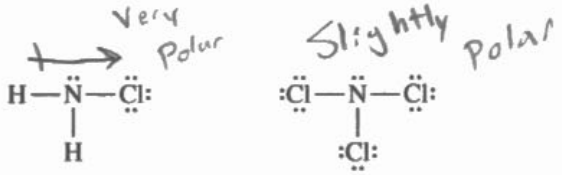
$$15.0\text{ g } NCl_3 \times \frac{1\text{ mol}}{120.36\text{ g}} \times \frac{32.9\text{ kJ}}{1\text{ mol}} = 4.10\text{ kJ}$$

Total for question 4 4 points

Question 4

Begin your response to **QUESTION 4** on this page.

4. Answer the following questions about the compounds NH_2Cl and NCl_3. The Lewis electron-dot diagrams of the two compounds are shown.



(a) Calculate the number of moles of NH_2Cl (molar mass 51.48 g/mol) present in 1.0 L of a solution in which the concentration of NH_2Cl is 0.0016 g/L.

$$\frac{0.0016\ g\ NH_2Cl}{L} \times 1\ L = 0.0016\ g\ NH_2Cl \left| \frac{1\ mol}{51.48\ g} \right.$$

$$= 3.1 \times 10^{-5}\ mol\ NH_2Cl$$

(b) NH_2Cl is highly soluble in water, whereas NCl_3 is nearly insoluble. Explain this observation in terms of the types and relative strengths of the intermolecular forces between each of the solutes and water.

Both of the solutes exhibit London Dispersion forces, dipole-dipole attractions, and Hydrogen bonding with water molecules. However, NH_2Cl is far more polar and therefore has much stronger dipole-dipole attractions with polar water molecules. Since they have more similar IMFs, water can better dissolve NH_2Cl than NCl_3.

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Q5119/12

Question 4

Continue your response to **QUESTION 4** on this page.

(c) The value of $\Delta H^{\circ}_{vaporization}$ for $NCl_3(l)$ is 32.9 kJ/mol. Calculate the amount of energy required to vaporize a 15.0 g sample of NCl_3 (molar mass 120.36 g/mol).

$$15\ g\ NCl_3 \left| \frac{1\ mol\ NCl_3}{120.36\ g\ NCl_3} \right| = 0.125\ mol\ NCl_3 \times \frac{32.9\ kJ}{mol}$$

$$= 4.10\ kJ$$

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Question 4

Begin your response to **QUESTION 4** on this page.

4. Answer the following questions about the compounds NH_2Cl and NCl_3. The Lewis electron-dot diagrams of the two compounds are shown.

(a) Calculate the number of moles of NH_2Cl (molar mass 51.48 g/mol) present in 1.0 L of a solution in which the concentration of NH_2Cl is 0.0016 g/L.

$1.0\,L \times \frac{0.0016\,g}{1\,L} \times \frac{1\,mole}{51.48\,g} = 3.1 \times 10^{-5}$ moles of NH_2Cl

(b) NH_2Cl is highly soluble in water, whereas NCl_3 is nearly insoluble. Explain this observation in terms of the types and relative strengths of the intermolecular forces between each of the solutes and water.

NH_2Cl is highly polar due to nitrogen and it has 2 Hydrogen bonds which are ~~tri~~ the strongest intermolecular forces whereas, NCl_3 is not as polar ~~and~~ because the unbonded electrons balance it out. Also, polar dissolves polar; in this case, water is polar and so is NH_2Cl.

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Q5119/12

Question 4

Continue your response to **QUESTION 4** on this page.

(c) The value of $\Delta H^{\circ}_{vaporization}$ for $NCl_3(l)$ is 32.9 kJ/mol. Calculate the amount of energy required to vaporize a 15.0 g sample of NCl_3 (molar mass 120.36 g/mol).

$$15.0\,g \times \frac{1\,mole}{120.36\,g} \times \frac{32.9\,kJ}{1\,mole} = \boxed{4.11\,kJ}$$

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Question 4

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4. Answer the following questions about the compounds NH_2Cl and NCl_3. The Lewis electron-dot diagrams of the two compounds are shown.

(a) Calculate the number of moles of NH_2Cl (molar mass 51.48 g/mol) present in 1.0 L of a solution in which the concentration of NH_2Cl is 0.0016 g/L.

$$\frac{0.0016\ g}{L} \left| \frac{1\ mol}{51.48\ g} \right| \frac{1\ L}{1\ mol} = 7.0 \times 10^{-4}\ moles$$

(b) NH_2Cl is highly soluble in water, whereas NCl_3 is nearly insoluble. Explain this observation in terms of the types and relative strengths of the intermolecular forces between each of the solutes and water.

NH_2Cl has hydrogen bonding and water also has hydrogen bonding so because these molecules both experience the same intermolecular forces water will be able to dissolve NH_2Cl. NCl_3 is nonpolar and also has covalent bonds so it will not dissolve in water.

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Q5119/12

Question 4

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(c) The value of $\Delta H^{\circ}_{vaporization}$ for $NCl_3(l)$ is 32.9 kJ/mol. Calculate the amount of energy required to vaporize a 15.0 g sample of NCl_3 (molar mass 120.36 g/mol).

$$\frac{15.0\text{ g } NCl_3 \mid 1\text{ mol} \mid 32.9\text{ kJ}}{\mid 120.36\text{ g} \mid \text{mol}} = 4.10\text{ kJ}$$

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Question 4

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 4 prompted students to perform various tasks concerning NH_2Cl and NCl_3 systems.

Part (a) asked students to perform a simple mathematical operation (Learning Objective SPQ-1.A, Science Practice 5.F from the *AP Chemistry Course and Exam Description*)—determining the moles of NH_2Cl in a volume of solution given the concentration of the solution (in units of g/L) and the molecular mass of the compound.

In part (b) students had the opportunity to earn 2 points. Students were asked to explain why NH_2Cl is very soluble in water, whereas NCl_3 is nearly insoluble. The explanation should identify the intermolecular interactions between water and both of the solutes (hydrogen bonding and dipole-dipole interactions) (SAP-5.A, 1.A). Students then had to compare the relative magnitudes of the intermolecular interactions between NH_2Cl/water and NCl_3/water to explain why NH_2Cl is more soluble (SPQ-3.C, 6.E).

Part (c) asked that students demonstrate mathematical skills by recognizing that moles of NCl_3 must be determined from the given mass, prior to determining the energy required to vaporize this sample (ENE-2.E, 5.F).

Sample: 4A
Score: 4

This response earned 4 points. In part (a) the point was earned for the correct setup and answer. In part (b) the first point was earned for correctly identifying hydrogen bonding intermolecular forces between each substance and water. The second point was earned for correctly relating the relative strengths of the intermolecular forces to solubility. In part (c) the point was earned for the correct setup and answer with correct units.

Sample: 4B
Score: 2

This response earned 2 points. In part (a) the point was earned for the correct setup and answer. In part (b) the first point was not earned because the intermolecular forces between each substance and water are not clearly identified. The second point was not earned because polarity is used to explain the solubility of NH_2Cl, rather than using the relative strength of the intermolecular forces between each solute and water to explain relative solubility. In part (c) the point was earned for the correct setup and answer with correct units.

Sample: 4C
Score: 1

This response earned 1 point. In part (a) the point was not earned for incorrectly using 22.4 L/mol in the conversion. In part (b) the first point was not earned because the hydrogen bonding intermolecular forces between NCl_3 and water are not identified. The second point was not earned

Question 4 (continued)

for incorrectly identifying NCl_3 as nonpolar to explain its relative solubility. In part (c) the point was earned for the correct setup and correct answer with units of kJ.