CollegeBoard
Advanced Placement
Program

Student Performance Q&A:

2008 AP® Chemistry Free-Response Questions

The following comments on the 2008 free-response questions for AP® Chemistry were compiled by the Chief Reader, Eleanor Siebert of Mount St. Mary's College in Los Angeles, California. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student performance in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question 1

What was the intent of this question?

This question was designed to probe student understanding of gases and gaseous equilibria. Part (a) required students to write the expression for K_p. In part (b) students were asked to determine the number of moles of $CO_2(g)$ given the volume, pressure, and temperature. This determination required the use of the ideal gas law. In part (c)(i) students had to select the correct data from the table and use Dalton's law of partial pressures to determine the pressure of $CO(g)$ at equilibrium. In part (c)(ii) students were asked to determine the value of K_p using equilibrium pressures. In part (d) they had to explain the effect of a catalyst on the total pressure of gases at equilibrium. In part (e) students were given a new set of initial conditions and asked to determine the direction the reaction would proceed to reach equilibrium.

How well did students perform on this question?

Generally, students performed in the middle range on this question. The mean score was 4.17 out of 9 possible points. Students often earned points in parts (b), (c)(ii), and (d). The most frequently earned point was in part (d), while the most frequently missed points were for part (e). Students often exhibited a better conceptual knowledge of gases than mathematical skills when using data.

What were common student errors or omissions?

Common student errors in part (a) included failing to express K_p in terms of pressure (typically substituting concentration) or copying the expression $K_p = K_c(RT)^{\Delta n}$ from the "Advanced Placement Chemistry Equations and Constants" sheet in the exam booklet and attempting to use it.

In parts (b) and (c) students often failed to recognize the significance of initial versus equilibrium pressures for their calculations. Also, students often made algebraic errors. In part (c)(i) students were frequently confused about when to use the stoichiometric relationship between the gases given in the reaction.

In part (e) students often did not use a calculation in the justification even though they were asked to do so; they also frequently used stoichiometric reasoning and/or Le Chatelier's principle instead of comparing the reaction quotient, Q, to K_p.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Teachers should ask students to write equilibrium expressions in their classroom assessments. They should also ask students to distinguish between a K_c expression and a K_p expression. The use of simulated lab data as a follow-up to labs may help students better distinguish between initial values of measurements and equilibrium values.
- Teachers should work with students to help them develop a qualitative and quantitative ability to justify predictions.
- Finally, teachers should stress to their students that they should read all of the parts of a question thoroughly and answer the question as it was written.

Question 2

What was the intent of this question?

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.

How well did students perform on this question?

Overall, students did reasonably well when answering this question. The mean score was 4.15 out of 10 possible points, and the distribution of scores was relatively even.

Students were generally successful on parts (a) and (b)(i), and responses that earned 1 to 2 points usually garnered them here. Part (b)(ii) proved a bit more challenging, as students frequently used an incorrect mass to calculate the number of moles of water of hydration and determine the formula.

In part (c) students usually recognized that the laboratory procedure error described would result in a calculation of too large a mass of water; however, many had difficulty providing an appropriate justification and consequently failed to earn the point.

In part (d) most students described a quantitative laboratory procedure for the isolation of a precipitate, but many did not elaborate sufficiently to earn full credit. While most students recognized filtration as the method of choice, they often did not include the necessary step of drying the precipitate prior to weighing, nor did they explain the need to determine the mass of the precipitate by difference. A significant proportion of students misinterpreted the intent of the question; these students attempted a mathematical explanation of the steps necessary to calculate the mass of $AgCl$ from the data.

In part (e)(i) students were generally successful with the calculation of the moles of $MgCl_2$; however, many used an incorrect value for the total mass of the sample in part (e)(ii) and so did not earn the final point.

What were common student errors or omissions?

(a) Students most frequently answered this part correctly. Common errors were:

- A description or restatement of the data provided, without explanation
- An unclear explanation of the term "constant mass"
- A description of the data as having high accuracy and/or precision

(b)(i) Students frequently answered this part correctly as well. Common errors were:

- Calculating an incorrect mass of water from the data (students often reversed the water and $MgCl_2$)
- Subtraction errors
- Failing to round the final answer appropriately and reporting an answer with the wrong number of significant figures

(b)(ii) Two points were available for this question, and students often earned one point for applying a mole ratio to end up with a hydrated formula. Common errors were:

- Using an incorrect mass to determine the moles of $MgCl_2$
- Failing to recognize that a mole ratio was required and applying the number of moles of water to the formula
- Misunderstanding the meaning of the term "formula" (some students tried to provide a balanced equation for a reaction between H_2O and $MgCl_2$ instead)

(c) Many students were able to correctly identify the effect of the error but unable to supply an appropriate justification. Common errors were:

- Confusion between the terms "hydrate" and "water"
- Not understanding that the hydrate was a solid and that water would not also "splash out"

(d) This was the most difficult part of the question for students. Common errors were:

- Omitting at least one of the required three steps (filtering, drying, or weighing the precipitate by difference)
- Stating only the need to weigh or mass the precipitate
- Not describing the steps in sufficient detail
- Referencing the hydrate procedure from the first part of the question

(e)(i) Many students earned at least one point in this part. Common errors were:

- Miscalculation of the molar mass of $AgCl$
- Failure to recognize the $1:2$ stoichiometric ratio between $MgCl_2$ and $AgCl$
- Not answering the question and calculating the mass of $MgCl_2$
- Using an incorrect mass of the sample from another part of the question
- Failing to round the final answer appropriately and reporting an answer with an incorrect number of significant figures

(e)(ii) Many students answered this question correctly. Common errors were:

- Using an incorrect value for the total mass of the sample
- Trying to calculate a percent error rather than the percent by mass
- Calculating the mass of $MgCl_2$ but not using it to calculate the percent by mass
- Failing to round the final answer appropriately and reporting an answer with an incorrect number of significant figures

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Have students perform the recommended laboratory experiments.
- Provide opportunities for students to engage in guided-inquiry experiments. Students need to practice the analysis of data collected in tabular form and also be able to recognize when data are valid.
- Give students laboratory experiences in which technique is important, as was the case in part (d). Students rarely mentioned that the precipitate should be washed and rinsed to remove the other soluble salts.
- Remind students that significant figures are important in calculations, and review the rules for addition and subtraction.
- Deemphasize the use of algorithms for numerical calculations. Students are often able to solve gravimetric stoichiometry problems but are unaware of the intermediate values calculated.

Question 3

What was the intent of this question?

This question tested a diverse set of student skills. Parts (a) and (b) were intended to assess the ability of students to understand the relationship among standard reduction potentials of half-reactions and the cell potential, and the relationship between the cell potential and the change in Gibbs free energy of the reaction. Part (c) assessed students’ ability to relate the change in entropy of the reaction to the phases of reactants and products given in the balanced equation. Parts (d), (e), and (f) required students to answer questions related to the kinetics of a different reaction; calculate reaction orders from experimental data; write a rate law that was consistent with the orders; and determine a rate constant. Those parts of the question were intended to assess the students’ understanding of kinetics and the meaning of reaction orders, and their ability to write and interpret a rate law.

How well did students perform on this question?

Because this question assessed a broad range of skills, the range of student performance was also quite broad. The mean score was 3.65 out of 9 possible points. Surprisingly, the modal score was 0, with 18 percent of the responses failing to earn any points and another 6 percent of papers left completely blank. Those students who were able to earn points on the question performed fairly well, and the distribution of scores from 1 through 9 was relatively even. Many students earned all of the points available on parts (a) through (c) but earned no points on parts (d) through (f), or vice versa; this suggests that one or more of the topics had likely been omitted or covered superficially in the students' courses.

What were common student errors or omissions?

In part (a) the most common answer was obtained by simply subtracting the values of $E°$ given, obtaining +0.28 V rather than the correct +0.96 V. Because the unit (V) was provided in the values, responses that omitted the unit still earned the point.

In part (b) common errors included:

- Identifying an incorrect number of electrons transferred in the reaction, with common errors of $n = 5$ (sum of electrons in each half-reaction) and $n = 22$ (sum of coefficients in balanced equation)
- Using $E°$ for one of the half-reactions (answer carried down from part [a] rather than the cell potential given)
- Giving incorrect or inconsistent units or omitting units altogether
- Omitting the algebraic sign of $\Delta G°$

In part (c) many students attempted to determine the +/– sign of $\Delta S°$ from the relationship $\Delta G° = \Delta H° - T\Delta S°$ and then use the value of $\Delta G°$ obtained in part (b). A small fraction of responses determined the incorrect sign of $\Delta S°$ by considering the total number of moles of products versus reactants and failing to look carefully at the phases.

In part (d) many students performed well, but common errors included:

- Incorrect algebra (e.g., $3^n = 9 \Rightarrow n = 3$)
- Failure to provide justification

In part (e) common errors included:

- Omission of rate constant
- Exponents that were inconsistent with values obtained in part (d)
- Writing an equilibrium expression rather than a rate law

In part (f) those students who wrote a well-formed rate law in part (e) also did well here. The most common errors included:

- Failing to include units or including incorrect units (e.g., $M\ s^{-1}$)
- Substituting inconsistent value from the experimental data
- Poor algebra and an inability to use scientific notation
- Confusion between the rate of reaction and the rate constant, k

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Student performance on tasks like part (a) might be improved by encouraging students to write an equation that relates the cell potential to those of the half-reactions.
- Emphasize "ballpark" values and the physical meaning of numerical quantities (e.g., students should recognize that $-360{,}000$ kJ mol^{-1} is an absurdly large value for the $\Delta G°$ of a chemical reaction).
- Give students practice writing and interpreting rate laws, with particular emphasis on units of reaction rates, rate constants, rates of formation, and concentrations.
- Emphasize the precise use of symbols and notation (e.g., mol versus m versus M, k versus K, parentheses versus brackets, and the appropriate use of superscripts and subscripts).

Question 4

What was the intent of this question?

This question was intended to assess students' ability to write both molecular and net-ionic equations and to recognize when each is appropriate. Various aspects of the question were intended to reinforce knowledge gleaned from the classroom and from experience in the laboratory.

How well did students perform on this question?

Students displayed a wide range of knowledge and skills in their responses to this question. The mean score was 6.81 out of 15 possible points. Scores covered the range from 0 to 15, with close to a perfect bell-shaped distribution curve. The most common scores were 4, 5, and 6, and there were relatively few blank papers.

What were common student errors or omissions?

Common student errors included:

- Showing insoluble substances, or substances stated to be solid or gaseous, in ionized form
- Showing gaseous forms as if in aqueous solution
- Including spectator ions in the same form on both sides of the equation
- Not balancing equations so that coefficients are in terms of lowest whole numbers
- Not canceling reagents that appear on both sides of the equation
- Confusing the terms "colorless" and "clear" ($CuSO_4$, for example, forms a clear but colored solution)
- Mistaking common formulas (e.g., writing "HCl_2" rather than "HCl," or "2Cl" rather than "Cl_2")
- Using inexact language (e.g., "phenolphthalein will show its basic color" rather than "phenolphthalein turns pink in basic solution")
- Reading the prompt inexactly (e.g., not writing the formula of a complex ion when directed to do so)
- Balancing by stoichiometry of atoms but not by charge
- Omitting an explanation or justification following an assertion in parts (a)(ii), (b)(ii), and (c)(ii)
- Writing more than one answer in the provided answer box

- Placing charges within formulas (e.g., "$H^{1+}Cl^{1-}$" rather than "HCl")
- Adding inappropriate products just to "balance" the equation
- Adding and omitting randomly the charges on species in the written reaction

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Give students practice with writing net-ionic equations. Emphasize fundamental knowledge and skills regarding equation writing, including elemental forms and common ions, especially polyatomic anions. Student responses often showed errors in the systematic presentation of chemical species, including soluble versus insoluble salts, strong versus weak acids or bases, and gaseous versus aqueous states. Some students also had difficulty with the art of balancing equations, neglecting to conserve either mass or charge.

- Encourage students to write balanced net-ionic equations to describe their work in the laboratory. A student who has performed an acid-base titration with phenolphthalein as an indicator is unlikely to forget the characteristic pink color of the indicator as the solution becomes basic at the titration's endpoint. Similarly, a student who has created a precipitate of $Al(OH)_3$ by adding strong base drop-wise to a solution containing aluminum(III) cation is apt to remember the excitement of redissolving that precipitate by continuing to add drops of strong base to form a complex ion. A student who has oxidized $HCl(g)$ with $O_2(g)$ in the lab is not following safe lab practices, but that student should have been taught that HCl is not ionized in the gaseous state.

- Remind students to refer to the resources available to them during the exam, specifically the "Periodic Table of the Elements" and "Standard Reduction Potentials in Aqueous Solution at 25°C" pages in the exam booklet, for memory prompts about the behavior of elements and common ions.

- Provide students with opportunities to practice writing about chemistry. Precise language is important. For example, many responses for part (a)(ii) were unclear as to whether the added acid reacted with the complex or the hydroxide ions from the ionized NaOH. Many descriptions of LeChâtelier shifts or limiting reactants were vague. A good observation in the lab is not "it changed color" but specifically what the color change was. It is not sufficient to say "the acid reacted with the ions." What ions? What reaction occurred? Instead, specify why the added acid affected the concentration of the complex ion. Pronouns should have unambiguous antecedents; sentences that might have made sense if written as "the acid reacts with the base and tends to neutralize the solution" were too often seen as a statement such as "it reacts with it and tends to neutralize it."

Question 5

What was the intent of this question?

This question was designed to assess student understanding of the structure and properties of atoms and molecules. In parts (a) through (c) students had to demonstrate their understanding of ionization energy and provide explanations for its variance among different atoms. In parts (d) through (f) students were required to sketch Lewis electron-dot diagrams, identify molecular shape and hybridization, and predict molecular polarity.

How well did students perform on this question?

The mean score was 3.92 out of 9 possible points, with scores of 4 and 5 both being modal. This question had a wide bell-shaped distribution of scores.

What were common student errors or omissions?

In part (a) the correct chemical equation was seldom obtained. Some responses attempted to develop a mathematical equation involving the given value of the first ionization energy.

In parts (b) and (c) the explanations that were to be made on the basis of nuclear charge and atomic size instead often involved discussions of periodic trends, electron configuration, or electronegativity.

In part (d) most students drew correct Lewis electron-dot diagrams. Performance varied when students attempted to use these diagrams to reason out the shape, the central atom hybridization, and then molecular polarity.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Students need to be able to discuss the factors determining the trends of atomic properties. They must also understand the difference between periodic trends and the explanation for what is responsible for such trends.
- Some students need help in distinguishing between the first-ionization energy and electron affinity.
- Students need to practice the reasoning sequence employed in understanding molecular structure: complete a Lewis electron-dot diagram, use this to determine the electron-pair orientation and thus the molecular shape, and then use the shape to find the central atom hybridization and molecular polarity. The role of symmetry in determining polarity needs to be stressed.

Question 6

What was the intent of this question?

This question explored the importance of intermolecular interactions in phase changes and dissolution. To earn full credit, a student had to identify the relevant forces involved in each process. In part (a) students had to explain that pyridine’s ability to hydrogen bond with water distinguishes its aqueous solubility from that of benzene. In part (b) students had to recognize that while ethanol and dimethyl ether (structural isomers) have similar dispersion forces, the hydrogen bonding between ethanol molecules leads to a higher boiling point. Part (c) required students to contrast the melting points of a network covalent solid (in which strong covalent bonds are broken in the melting transition) and a molecular solid (in which only relatively weak intermolecular attractions must be overcome). In part (d) students had to recognize that the London/dispersion interactions between Cl_2 molecules must be greater than the total intermolecular forces between HCl molecules, and then attribute the difference to the larger number of electrons in the Cl_2 molecules.

How well did students perform on this question?

Students did poorly on this question. The mean score was only 1.86 out of 8 possible points. Both the median and modal scores were 1. Answers revealed a widespread misunderstanding concerning the differences between the interactions between molecules and the bonds that hold atoms together.

What were common student errors or omissions?

In all parts of the question, many students showed uncertainty about the distinctions between molecules and atoms, and between intermolecular forces and covalent (intramolecular) bonds. Many responses contained the ambiguous phrase “the forces holding the molecules together” or similar constructions, and it was difficult for Readers to determine whether the students intended to refer to inter- or intramolecular forces.

Part (a): Many students said that pyridine molecules “dissociated” or “came apart” when they dissolved in water, while the benzene bonds were so strong that they could not come apart. Students often attributed the solubility of pyridine to the solubility of ammonium or nitrate compounds. Appropriate discussions of the nature of the interaction between pyridine and water were rare; the adage that “like dissolves like” was used by a vast majority of the students, but it did not by itself earn credit because it was not an explanation or a discussion of the interaction between either of the solutes and water.

Part (b): The fundamental error made in a plurality (if not a majority) of the responses was that the covalent bonds within dimethyl ether and ethanol must be broken for the material to boil. A very common answer indicated that the C–C bond in ethanol was stronger than the C–O bonds in dimethyl ether, so that more energy was needed to break apart ethanol. A variation on this theme was to say that ethanol’s oxygen was easier (or harder) to remove than the (protected, less-conspicuous, or less-exposed) oxygen in the center of dimethyl ether.

Students frequently identified the (covalent) O–H bond in ethanol as a hydrogen bond, and they cited the ease of breaking the O–H bond in ethanol as the reason for the difference in boiling points (indeed, students often identified any covalent bond to hydrogen as a hydrogen bond). Students often referred to ethanol’s hydrogen bonding as “the strongest bond,” stronger than any of dimethyl ether’s covalent bonds. Dimethyl ether was almost uniformly (and incorrectly) classified as nonpolar, and many students attempted incorrect explanations of boiling point differences based on the apparent linearity of dimethyl ether or the length of the hydrocarbon chain in ethanol.

Part (c): A very common error based the difference in melting points on the covalent bond orders in Lewis electron-dot diagrams for SO_2 and SiO_2 molecules. Comparison of covalent and ionic bond strengths was another common approach. Differences in electronegativities among the three elements (S, Si, O) were frequently cited, as were their relative positions on the periodic table. The properties of elemental S, Si, and O were also repeatedly invoked.

Many responses displayed the misunderstanding that “network covalent bonds are stronger than regular covalent bonds,” rather than comparing the network covalent bond strength in SiO_2 to the strength of the intermolecular forces between SO_2 molecules.

Students often classified SiO_2 as an ionic compound, and many responses referred to Si as a transition metal.

Part (d): It was apparent that many students are fundamentally confused about the difference between intramolecular Cl–Cl and H–Cl bonds and the intermolecular interactions between Cl_2 and HCl molecules. Responses often attributed double bonds to Cl_2 (and HCl), and comparisons between the triple (or quadruple) bond in Cl_2 and the double bond in HCl were common. The Cl_2 molecule was often said to be polar, while HCl was nonpolar. Students often attributed some property (or properties) to Cl_2 because "it is diatomic." Students often cited periodic trends or positions of H and Cl on the periodic table.

Students interchangeably identified Cl_2 and HCl as ionic, polar, or nonpolar and as having ionic bonding, covalent bonding, hydrogen bonding, dipole-dipole, ion-dipole, and dispersion forces. Any selection of these forces, in any combination or order, could be found as students tried to justify the difference in boiling points. Responses frequently tried to invoke the dissociation of HCl as a strong acid to explain its low boiling point.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

Students have clearly been exposed to the material covered in this question. While they used the correct vocabulary, they generally used it incorrectly. The correct phrase "network covalent bonds" appeared in answers to part (c), for example, but the subsequent prose showed that students did not know what it meant. The bonds between atoms in molecules must be distinguished from the interactions that keep the molecules attracted to each other. The forces within a molecule are different from the forces between them. Phrases like "the intermolecular forces within the molecule" illuminate a major misunderstanding that must be addressed. The phrase "the forces holding molecules together" (and similar constructions) is ambiguous and should be avoided in favor of clear language, such as "forces between molecules" and "forces within molecules."