CollegeBoard
Advanced Placement Program

Student Performance Q&A:

2005 AP® Chemistry Free-Response Questions

The following comments on the 2005 free-response questions for AP® Chemistry were written by the Chief Reader, John Gelder of Oklahoma State University in Stillwater. 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 test students' understanding of solution equilibria involving weak acids. Students were asked to write the K_a expression for a weak acid, to determine the pH of a solution of that acid, and to determine the concentrations of species in a buffer solution of that acid. The students were then asked to calculate K_b for the conjugate base of a different acid given the hydroxide concentration of a solution of a sodium salt of that acid, and then to calculate K_a for that acid from the K_b for the conjugate base. Finally, the students were asked to compare the strengths of two acids and explain the difference.

How well did students perform on this question?

This was a required question. The mean score was 5.58 out of a possible 10 points. Many students performed well, and scores from 6 to 10 were not uncommon. Most students earned the point in part (a). The point least often earned was the buffer calculation point in part (c)(ii).

What were common student errors or omissions?

Part (a): Most students did this part correctly. The most common error was to miss the charges on the ions.

Part (b): Most students did this part correctly. The most common error was to treat the acid as a strong acid with $pH = -\log(0.265)$.

Part (c)(i): Many students neglected to include the mass of sodium in the molar mass of sodium propanoate, which was needed to calculate the concentration of propanoate ion. Some students added the concentration of the salt's propanoate ion to that of the propanoic acid.

Part (c)(ii): Many students did not recognize that this was a buffer problem and tried to set it up as a simple acid equilibrium problem. Many students who recognized that this was a buffer problem tried to do the calculation using the number of moles of propanoate ion and the molarity of the acid.

Part (d)(i): The most common error was to set up the problem as $K = \dfrac{(0.309)(4.18 \times 10^{-6})}{(0.309)}$.

Part (d)(ii): Most students who calculated a value for K_b were able to use the equation $K_w = K_a \times K_b$ to calculate K_a.

Part (e): Many students tried to explain the relative strengths using only pH (without also stating that concentrations must be equal). Some students did not know which value of K_a that they referenced was the larger number.

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 make sure that their students:

- read the question carefully;
- represent ions with the correct charge;
- clearly distinguish between number of moles and molarity when doing buffer problems;
- learn the value of K_w (even though it is included in the list of equations and constants in the exam booklet);
- set up problems clearly;
- circle answers; and
- use brackets for molar concentrations.

Teachers should make sure their students understand:

- that the Henderson-Hasselbalch equation does not apply to every acid-base equilibrium problem;
- that pH equals pK_a for weak acids only under very specific conditions;
- that pH is not equal to $[H^+]$; and
- how acid strength, K_a, and pK_a are related.

Question 2

What was the intent of this question?

This question was designed mainly to test students' ability to solve multistep stoichiometry problems. Starting with combustion analysis data, students were first asked to calculate the mass of each of the elements in a sample of a compound and then to find the compound's empirical formula. The students then needed to use colligative property data to find the molar mass and explain how to find the molecular formula. In the last part of the question, students were expected to identify the functional group that accounts for the low pH.

How well did students perform on this question?

Approximately 40 percent of students selected question 2. The mean score was 2.83 out of a possible 9 points. Students tended to do better on parts (a)(i), (a)(ii), (b)(i), and (c) than on parts (b)(ii) and (d).

What were common student errors or omissions?

Part (a)(i): Students did best on this part. Common errors included not multiplying the number of moles of H_2O by 2 to find the number of moles of H, and calculating the mass of O in the products, not in the original sample. Some students did not earn credit because their answers had no associated setup or reasoning.

Part (a)(ii): Many students had difficulty finding the necessary mole ratios and scaling these into the correct empirical formula. A common error was to round mole ratios to the nearest integer.

Part (b)(ii): Many students were confused as to how to handle the mass of the solvent and were unable to calculate the molar mass.

Part (c): Some students did not earn credit because they indicated that the empirical formula mass should be divided by the molar mass.

Part (d): Most of the common functional groups were given as answers. Some students used the pH to calculate $[H^+]$ but did not identify any group as being responsible for the observation.

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 are encouraged to:

- reinforce stoichiometry skills throughout the year, making the point that mole-based calculations are a component of most quantitative chemistry topics;
- require the use of setups throughout the course;
- emphasize that monitoring the units in a problem helps in solving the problem; and
- include more multistep problems in class work and assignments.

Question 3

What was the intent of this question?

This question was designed to test students' understanding of chemical kinetics. The students were provided with two sets of kinetics data in tabular form and asked a series of questions about each set. For the first set, they were asked to determine the order of reaction for each of the two reactants, to write a consistent rate law, and to determine the value of the rate constant, *k*, and its units. For the second set, they were asked to label the *y*-axis for a linear plot of a catalyzed first order reaction, to give the units of the rate constant, and to draw a line to represent the uncatalyzed reaction.

How well did students perform on this question?

Approximately 60 percent of students selected question 3. The mean score was 4.8 out of a possible 9 points. There were few scores of 0 and 9 but an approximately even distribution of scores 1 through 8.

What were common student errors or omissions?

Parts (a)(i) and (a)(ii): Some students gave an order of zero for the hypochlorite ion, saying that there were no two experiments with identical iodide ion concentrations. A variety of other orders were given as answers (third order for iodide ion and fourth order for hypochlorite ion were fairly common). Some students did not show their work to support their choice of orders and thus did not earn any points for this part. Some students simply referred to the coefficients of the balanced equation as the orders of the reactants.

Part (b)(i): A common error was to simply indicate that $k = [I^-]^x [ClO^-]^y$.

Part (b)(ii): The responses included a wide variety of incorrect units that were frequently inconsistent with the rate law given in part (b)(i). It seemed that many students came back to this problem after time had been called for part A of section II and had difficulty in carrying out these relatively simple calculations without a calculator.

Part (c)(i): The most common label for the vertical axis was $[H_2O_2]$.

Part (c)(ii): Many units other than min^{-1} were given for the rate constant.

Part (c)(iii): Common errors included lines with pronounced curvature, lines sloping in the wrong direction, and incorrect starting points. Many students drew a line with a greater negative slope rather than a smaller negative slope.

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 are encouraged to:

- drill students in the skill of unit analysis to produce the correct units for the rate constant *k*;
- provide opportunities for students to perform calculations by estimation and approximation without the use of a calculator;
- assign more varied types of kinetics problems, including those with integrated rate law data;
- instruct students in graphical analysis of kinetics data; and
- remind students to read both options of choice questions carefully before starting to write responses and to follow directions carefully.

Question 4

What was the intent of this question?

This question was designed to assess students' familiarity with chemical nomenclature, knowledge of common classes of chemical reactions, and ability to apply their knowledge in predicting the product(s) of a variety of chemical reactions.

How well did students perform on this question?

The most popular choices were the displacement of nickel ions from solution by zinc metal, reaction (a); the combustion of ethyne, reaction (c); and the precipitation of lead(II) iodide, reaction (h). Students generally scored quite well on this question, with a mean score of 8.22 out of a possible 15 points. There was a broad distribution of scores.

What were common student errors or omissions?

Reaction (a):

- Including of nitrate ion on reactant and/or product side of the equation
- Giving an incorrect charge on zinc ion or, less commonly, nickel ion

Reaction (b):

- Failing to recognize reaction as a complex ion formation, resulting in a single product
- Including potassium in reactant (or product)
- Giving an incorrect charge on product

Reaction (c):

- Failing to represent ethyne correctly
- Omitting oxygen as reactant, or representing oxygen as "air"

Reaction (d):

- Treating acetic acid as a strong acid or calcium carbonate as a dissociated compound
- Failing to decompose carbonic acid on the product side or writing calcium acetate as a molecular product

Reaction (e):

- Representing lithium as an ion
- Representing nitrogen as atomic
- Giving an incorrect chemical formula for lithium nitride
- Representing lithium nitride product as ions

Reaction (f):

- Giving an incorrect chemical formula for ammonia
- Failing to realize that a Lewis acid/base complex is formed, and treating the reaction as a double replacement reaction

Reaction (g):

- Including sodium ions on reactant side
- Confusing sulfur trioxide and sulfite ion

Reaction (h):

- Expressing reactants and product(s) in molecular form—writing a molecular equation rather than a net-ionic equation
- Failing to balance charge in formulas, or failing to know the correct charge of nitrate or iodide ions

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?

Emphasize the importance of the following with your students:

- knowing the solubility rules;
- recognizing the difference between a double replacement equation and a net ionic equation;
- understanding that weak acids should be expressed in un-ionized form;
- writing formulas of compounds correctly;
- memorizing charges of common cations and anions (including oxoanions);
- referring to the periodic table and table of standard reduction potentials available for reference during part B of the AP Exam; and
- writing only the final net-ionic equation in the answer box and removing spectator ions.

Also, remind students:

- that balancing equations may be time-consuming and is not rewarded;
- that phase notation is not rewarded; and
- that only items appearing in the answer box are scored.

Review chemical equations throughout the year in connection with other material; for example:

- synthesis reactions in connection with periodicity and properties of elements;
- decomposition reactions in connection with thermodynamics and entropy;
- redox reactions in connection with electrochemistry;
- acid/base reactions in connection with equilibrium;
- complex ion and Lewis acid/base reactions in connection with molecular structure and equilibrium; and
- combustion reactions in connection with thermochemistry.

Question 5

What was the intent of this question?

This question was intended to test students' understanding of descriptive chemistry in some common laboratory experiments. Students were first asked to predict the results of inserting a glowing splint into samples of nitrogen, hydrogen and oxygen gases, and then to predict the pH that would result from the combinations of the oxides of calcium, silicon, and carbon with water. Students were then presented with a partially completed grid of the results of combining three solutions and asked to identify the solutions and predict the results of another combination.

How well did students perform on this question?

The mean score was 3.24 out of a possible 9 points. Points were earned in a variety of ways; it was often clear which procedures a particular student had seen, and which were unfamiliar.

What were common student errors or omissions?

Part (a): For N_2, a common error was giving "no reaction" or "nothing happens" as a response, rather than recognizing that the ember will be extinguished. For O_2 and H_2, many students were not explicit as to what would combust, the gas or the splint.

Part (b): Most students seemed to be unfamiliar with the concept of acidic and basic anhydrides. Although a few recognized SiO_2 as quartz or glass, most did not recall that SiO_2 is insoluble and therefore would not affect the pH. Many students gave incorrect formulas for $Ca(OH)_2$, and H_2CO_3 or HCO_3^- (although correct formulas were not required to earn points for this part). Many students gave H_2 or O_2 as products of these reactions.

Parts (c)(i), (c)(ii), and (c)(iii): Many students had difficulty identifying insoluble and soluble combinations of ions. Faced with the higher level of difficulty required by working from products back to reactants, many students were unable to successfully identify the unknowns. In addition, many students who managed to identify silver sulfide as the black precipitate wrote AgS instead of Ag_2S as the formula. In addition, there were many responses with students writing formulas with the wrong ion (in particular, sulfite or sulfate instead of sulfide).

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?

- Increase the number of hands-on experiences.
- Encourage students to be more explicit in describing observations.
- Urge students to look carefully at the periodic table to determine proper combining capacities of ions and to develop a habit of writing correct formulas.
- Reinforce general solubility rules.
- Include oxide behavior as part of an exam on periodic trends.
- Emphasize knowing the charges of common cations and anions (including oxoanions).
- Emphasize reading prompts carefully, and give students practice throughout the year with the AP Exam format.

Question 6

What was the intent of this question?

This question tested students' ability to draw Lewis structures and predict geometry, bond angles, and hybridization from the structures. Students were also asked to determine the number of sigma and pi bonds in a molecule and to use formal charge to predict the best Lewis structure for a molecule.

How well did students perform on this question?

Almost all students attempted this required question. The mean score was 4.97 out of a possible 9 points.

What were common student errors or omissions?

Part (a): Students showed unusual dot and bond notation. Some students left lone pairs of electrons off the fluorine atoms in these structures, and some either omitted or added an extra lone pair of electrons around sulfur in SF_4.

Part (b)(i): Many students predicted that the bond angle of F–C–F in CF_4 was 90°.

Part (b)(ii): The electron configuration was often given instead of the hybridization.

Part (b)(iii): Many students confused the electronic shape with the molecular shape.

Part (c)(i): Many students predicted that the number of sigma bonds in OPF_3 was three.

Part (c)(ii): Most students were not able to calculate and/or apply formal charge in predicting the better Lewis structure for OPF_3. There was significant overemphasis given to the "octet rule" and "happy" electrons.

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?

- Present the standard notation for dots and bonds in Lewis structures.
- Limit the use of the "octet rule" and avoid discussing "happy" molecules, ions, and electrons.
- Stress that molecules are three-dimensional and that bond angles should reflect this.
- Stress the difference between electronic and molecular structure.
- Present the standard names for specific shapes—"sawhorse" is not the same as "seesaw."
- Have students practice determining hybridization and number of sigma and pi bonds in molecules.
- Have students practice calculating formal charge in order to determine the best Lewis structure for a molecule.

Question 7

What was the intent of this question?

This question was designed to test students' knowledge of a variety of concepts, including intermolecular forces and boiling points, bonding and melting points, quantum numbers, why ionization trends on the periodic table occur, isotopes, and an isotope's relationship to the average atomic mass.

How well did students perform on this question?

The mean score was 3.64 out of a possible 8 points. Most students earned two of their points in parts (d)(i) and (d)(ii). In general, students had more trouble in the parts requiring explanations (parts (a)(ii), (b)(ii), (c)(ii), and (d)(ii)).

What were common student errors or omissions?

Part (a)(i): Many students included covalent bonds, polar covalent bonds, or ionic bonds, or discussed intramolecular bonds. Many indicated incorrectly that the intermolecular force was a dipole moment, an induced dipole, or a London dispersion force.

Part (a)(ii): Many students recognized that they should use their answer to part (a)(i) in their explanations for part (a)(ii). Two common errors were indicating that the hydrogen bonding was between the nitrogen atoms and hydrogen within a molecule, and comparing hydrogen bonding to an intramolecular interaction such as covalent bonding.

Part (b)(i): A common error was to indicate that $NaCl$ was ionic but that KCl was covalent, or that both were covalent. Another error was to include terms such as single bonds, sigma bonds, pi bonds, or polar bonds.

Part (b)(ii): Many students discussed molecules instead of focusing on the difference between the sizes of the Na^+ ion and the K^+ ion. Some students attributed the difference to bond strength, the degree of covalency between the atoms, or differences in electronegativity. Another common error was to use an argument based on the smaller atomic mass of Na^+ compared to K^+.

Part (c)(i): A common error was to give electron configurations or all four quantum numbers without designating which number represented n. Other common errors were to give the number of valence electrons, the number of p electrons, or the third quantum number as the value of n.

Part (c)(ii): A common error was to simply state that there is a trend of increasing ionization energy from left to right on the periodic table, or to reiterate the trend in some way. Other incorrect arguments were based on electron configurations and having half-filled shells, less than half-filled shells, or only needing one electron to complete the shell.

Part (d)(i): Some errors indicated a lack of understanding of what an isotope is. Some students chose Eu (atomic number 63) or Gd (atomic number 64), and some indicated that each isotope represented a different element. Other elements chosen included Zn, Co, Fe, and Ni. The elements I and Te were also selected, based on students adding together the given isotopic masses.

Part (d)(ii): A common mistake was to say that 63.55 was closer to 64.93 than it was to 62.93 (a math error). Other mistakes included indicating that the lighter isotope was more stable, had fewer neutrons, or was less radioactive. Another conceptual error included the indication that an isotope was an ion, and that Cu(II) was more common than Cu(I).

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?

- Emphasize vocabulary: atom, ion, formula unit, molecule, atomic vs. ionic radius, intermolecular vs. intramolecular, ionic vs. covalent, isotope, etc.
- Continue to discuss the relationship between chemical principles and experimental/measured properties. It was difficult to discern in many student responses if they understood the relationship.
- Teachers should stress that the arrangement of the periodic table is a consequence of the structure of the atom, and that atomic structure is not a result of placement on the periodic table. (Generally, students attributed properties in all parts of the question to the position of the elements on the periodic table, rather than addressing the question in terms of chemical principles.)
- Give students practice working math problems without a calculator. Many students made math errors in part (d)(ii).
- Emphasize that students should read the problem carefully, and if a question gives an example, they should follow the example (as in part (c)(i), where $n = 1$, $n = 2$, etc.).
- Tell students to write their answers in the lined spaces provided and not between the lines of the exam questions.
- Emphasize that restating a trend does not explain the chemical principles behind the trend.
- Remind students to write legibly.

Question 8

What was the intent of this question?

This question was designed to test students' ability to apply thermodynamic concepts and to make electrochemical predictions based on reduction half-reactions.

How well did students perform on this question?

The mean score was 2.99 out of a possible 8 points. Students did best on part (d)(iii), and most found parts (d)(i), (d)(ii), and (d)(iv) very difficult.

What were common student errors or omissions?

Part (a): Many students tried to use incorrect justifications ($\Sigma G_{prod} - \Sigma G_{react}$, $\Delta G = \Delta H - T\Delta S$, $\Delta G = -nFE°$, etc.).

Part (b): Many students tried to use incorrect justifications ($\Sigma S_{prod} - \Sigma S_{react}$, since $\Delta G < 0$ then spontaneous reactions always have $\Delta S > 0$, etc.).

Part (c)(i): Some students indicated that the increase in temperature means that the reaction is exothermic, so $\Delta H < 0$. Other incorrect justifications involved $\Sigma H_{prod} - \Sigma H_{react}$, or using $\Delta G = \Delta H - T\Delta S$ to determine the sign of ΔH.

Part (c)(ii): Many students did not relate ΔH to $T\Delta S$ but rather to ΔS . Many students used incorrect logic in interpreting the effect of the signs in the $\Delta G = \Delta H - T\Delta S$ equation.

Part (d)(i): The most common error was to indicate that metallic sodium was being oxidized.

Part (d)(ii): The most common error was to use the reduction of I_2 to $2\ I^-$ for the reduction half reaction.

Part (d)(iv): Most students knew that $\Delta G > 0$ but were not able to justify it (revert back to $\Delta G = \Delta H - T\Delta S$, $\Sigma G_{prod} - \Sigma G_{react}$, etc.). Many students used $\Delta G = -nFE°$ and said that since $E° > 0$, $\Delta G < 0$.

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 make sure that students:

- can predict the sign of ΔG , ΔH , or ΔS from other information and explain their reasoning clearly;
- understand the significance and effects of the signs of the terms in $\Delta G = \Delta H - T\Delta S$;
- realize that not all exothermic reactions are spontaneous; and
- understand that water can participate in the oxidation-reduction reaction.