CollegeBoard
Advanced Placement
Program

Student Performance Q&A:

2006 AP® Chemistry Free-Response Questions

The following comments on the 2006 free-response questions for AP® Chemistry were written 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 a required equilibrium problem designed to assess students' understanding of solubility and principles of solubility equilibrium. Students were expected to write an expression for the K_{sp} from the solubility equation, determine the stoichiometric relationship between concentrations of ions, and calculate the value of the K_{sp} . They were asked to assess the effect of different volumes of solution on the concentrations of ions in a saturated solution and the effect of adding a soluble salt containing a common ion. The last part of the question assessed students' ability to calculate concentrations of ions from dilution data and to calculate and interpret the value of Q in comparison to K_{sp} .

How well did students perform on this question?

Students did a good job answering the question, earning a mean score of 4.19 out of a possible 9 points. There was a very flat score distribution, with each score (0–9) accounting for 8 to 12 percent of the responses (excluding blanks). The comparatively large percentage of 8s and 9s indicated that many students had mastered the tested concepts. The points were well distributed among the four parts of the problem, though many responses that scored in the midrange (5–6) earned most of the points on parts (a) and (d). Students who earned 1–3 points usually earned them in part (a). Part (b) was the most challenging for students; most of the students who earned 8 points failed to earn the 1 point for part (b).

What were common student errors or omissions?

Part (a)(i): Some students included $[PbI_2]$ in the equilibrium constant expression, and some omitted the charges on Pb^{2+} and I^-.

Part (a)(ii): Some students indicated that $[I^-] = (1.3 \times 10^{-3})^2 = 1.7 \times 10^{-6}$, and some made errors with significant figures.

Part (a)(ii) and (a)(iii): Some students made errors with significant figures.

Part (b): Many students indicated that the concentration was inversely (or directly) proportional to volume. Many stated (correctly) that concentration is independent of volume but failed to refer to the saturated solution, equilibrium, or K_{sp} .

Part (c): Many students stated that solid NaI would have no effect on the equilibrium constant. Incorrect explanations included indicating that the change in volume causes a dilution that affects $[Pb^{2+}]$, that the added Na^+ crowds the Pb^{2+}, and that if $[I^-]$ increases $[Pb^{2+}]$ also has to increase.

Part (d)(i): Some students failed to use the concentration and volume data given and calculated $[Ba^{2+}]$ and $[CrO_4^{2-}]$ (incorrectly) from the given K_{sp} .

Part (d)(ii): Many students indicated that since $Q \neq K_{sp}$, no precipitate forms, while others indicated that if $[Ba^{2+}] = [CrO_4^{2-}]$, no precipitate forms.

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?

- Stress the distinction between amount (moles), volume (liters), and concentration (molarity), and which (if any) of these quantities remains unchanged in various lab situations (dilution, equilibrium, etc.).
- Stress the interpretation of numerical data and “reasonable” values. Students should be able to estimate order-of-magnitude values for quantities without performing calculations and should be able to recognize chemically absurd values.
- Differentiate between experimental contexts that are described by different types of equilibrium constants: K_{eq} , K_p , K_c , K_{sp} , K_a , K_b .
- Students should understand reaction stoichiometry and be able to use that to calculate the concentration of molecular and ionic species in solution.

Question 2

What was the intent of this question?

The intent of this question was to test students’ knowledge of basic thermodynamic relationships, including enthalpy, entropy, and free energy changes, and the equilibrium constant associated with a chemical reaction. The first task was to calculate the values for enthalpy, entropy, and free energy changes from the information provided. Students were asked what the calculated thermodynamic quantities implied for the spontaneity of the reaction given, $CO + \frac{1}{2} O_2 \rightarrow CO_2$, and to calculate the thermodynamic equilibrium constant.

How well did students perform on this question?

The mean score was 5.64 out of a possible 9 points. Many students performed well on the calculations for enthalpy, entropy, and free energy changes, although there were many common errors with mathematical operations and significant figures. Failure to make unit conversions so that the units were consistent within a calculation was a very common error. The implication of the free energy change was generally well handled. Students found the calculation of the thermodynamic equilibrium constant to be the most challenging part of the problem.

What were common student errors or omissions?

Part (a): Most students were successful in either applying Hess's Law or using enthalpies of formation to calculate the enthalpy change, $\Delta H°$, for the reaction. Students who applied Hess's Law often inverted the numbers; i.e., product values were subtracted from reactant values rather than the correct "products minus reactants." Sign errors and missing units were also common.

Part (b): Most students were successful in calculating the entropy change, $\Delta S°$, for the reaction. The two most common errors were the omission of the stoichiometric coefficient of ½ for oxygen and the inversion of the correct equation to incorrectly use $S°_{reactants} - S°_{products}$. Sign errors and missing units were also common.

Part (c): Most students knew that the calculation of the free energy change, $\Delta G°$, is done by applying the Gibbs free energy equation, $\Delta G° = \Delta H° - T\Delta S°$. The most common error was the failure to reconcile the kilojoules in the units for $\Delta H°$ with the joules in the units for $\Delta S°$. Sign errors, significant figure errors, math errors, and failure to provide units for the answer were also common.

Part (d): Many students were able to recognize the implications of the calculated thermodynamic values for the spontaneity of the reaction. It would appear that, for the most part, they do understand the implications of the sign of the Gibbs free energy change for a reaction.

Part (e): The calculation of the thermodynamic equilibrium constant was clearly the most difficult part of this problem for students. Many did not know the relationship between Gibbs free energy and the equilibrium constant, $\Delta G° = -RT \ln K$. Many students failed to use the correct value of R (8.31 J/mol·K = 0.00831 kJ/mol·K) or to reconcile the units in R with those in $\Delta G°$. Sign errors and math errors involving ln (or log) or calculator use were also common.

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?

- Review and reinforce all of the thermodynamic equations and their interrelationships.
- Review the implications for a reaction of the thermodynamic values, especially ΔG, $\Delta G°$, and K.
- Be sure that students recognize the relationship between thermodynamic values ($\Delta G < 0$ and a reaction being spontaneous; $\Delta G° < 0$ corresponds to $K > 1$, for example).
- Review which value for constant R is appropriate for the calculation of thermodynamic values.
- Encourage students to show all work and follow signs carefully.

- Urge students to include and reconcile units in all their work. Emphasize that 1 kJ = 1000 J.
- Emphasize and review significant figures.

Question 3

What was the intent of this question?

Students were asked to use different types of data to determine the empirical formula of a compound. With a different set of data, students were asked to determine a molecular formula.

How well did students perform on this question?

This was a choice question, with approximately 34 percent of the students choosing it. The mean score was 4.12 out of a possible 9 points. The most commonly earned point was (a)(ii), where the student used the given percent composition to determine the number of grams of nitrogen in the sample. The numbers calculated in parts (a)(i), (a)(ii), and (a)(iii) had to be used in part (a)(iv). It was possible to get all the answers in parts (a)(i), (a)(ii), and (a)(iii) incorrect and still receive all 3 points in part (a)(iv). More students earned points in part (a) than in part (b). This may have been partially due to problems with time management; many students just stopped in the middle of the problem.

What were common student errors or omissions?

In all parts of this question, many students did not get credit for correct answers because no work was shown. Another common error was not using the proper number of significant figures.

Part (a)(i): Students used a variety of methods to solve for the number of grams of carbon in the sample. Most used the gram ratio of carbon to carbon dioxide to solve. Some students used the original sample mass instead of the CO_2 mass to find the amount of carbon. Another error was using the wrong molar mass for carbon dioxide. It was also very common to see students round molar masses to whole numbers. Another error was to take the mass of the sample and divide by 3 because there are three atoms in CO_2 .

Part (a)(ii): Some students used the given mass of carbon dioxide to find the grams of nitrogen.

Part (a)(iii): Many students forgot to subtract the given hydrogen mass from the sample or subtracted from the amount of CO_2 given. Other students tried to calculate the oxygen mass in the sample from the percent oxygen in CO_2 , assuming all the oxygen in the CO_2 was in the original sample.

Part (a)(iv): Common errors included dividing by the smallest numer of grams and then determing the empirical formula with improper rounding, such as rounding 8.5 to 9. Some students divided by the molar mass of O_2 , N_2 , and H_2 . Another error in parts (a)(iv) and (b)(ii) was to multiply only certain elements in the empirical formula by a factor. For instance, CH_2Br when multiplied by 2 might become CH_4Br.

Part (b)(i): Some students used the wrong value of R to calculate the molar mass. Several methods were used to find the molar mass. All correct methods with logical work were accepted.

Part (b)(ii): After finding the multiplier, several students multiplied it by the empirical formula from part (a)(iv) instead of the empirical formula identified in part (b) of the question.

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?

- Require students to show <u>all</u> their work in all parts of a problem, and require them to be neat and organized in their work. It is helpful if the work follows a logical progression so that it is clear to the Reader where a number comes from. Many students earned zeros in several parts due to lack of work. Correct answers miraculously appearing on a paper with incorrect work received no credit. On a calculation problem, showing work does NOT mean writing a paragraph explaining the steps done in the calculation. After showing work, many students wrote lengthy explanations of how to do the calculation.
- Remind students not to round internally in an answer. Significant errors can be introduced by rounding at inappropriate times in the calculation. These errors were compounded in subsequent calculations requiring use of that answer.
- Caution students to be careful and double check for reasonable answers. If a student subtracts and gets a negative mass or calculates a molar mass less than the empirical mass, the student should recheck the work.
- Have students practice with a variety of problems from various types of data. Question 3 gave masses to four significant figures. When given lab data to 0.001 g, students should use atomic molar masses with significant figures to match or exceed those in the given data. In solving this problem, students need to use one or two decimal digits given on the periodic table provided for the exam to find the number of moles—not molar masses of 12, 16, etc. It would be helpful if students were familiar with this table and used it all year.
- Remind students to carefully check their work. Many simple mathematical errors were made, including transposing digits or just dropping digits. For instance, a student would use 2.24 grams of CO_2 when 2.241 grams was given. Several students incorrectly rearranged the equation $PV = nRT$ when trying to find the molar mass.
- Make sure students clearly understand the difference between an empirical mass and molar mass; several students calculated the empirical mass of CH_2Br and indicated it was the molar mass.
- Practice time-management skills and give practice timed sections so students are familiar with the pace at which they must work to complete this section. It was very apparent that many students ran out of time with their calculators and could not finish the problem.

Question 4

What was the intent of this question?

The intent of this question was to determine whether students could apply general principles of chemical reactions in order to predict the products of a variety of reactions. The students were given names of reactants for eight different reactions, including decomposition, complex ion formation, weak acid/strong base, weak acid/weak base, redox, Lewis acid/base, precipitation, and combustion reactions. In this and former versions of the AP Chemistry Exam, the students were only required to write reactants and products as net ionic equations when applicable; balancing and states of matter were not scored.

How well did students perform on this question?

The students did well on this question, with a mean score of 7.49 out of a possible 15 points. Perfect to near perfect responses were not uncommon. Some students could not write the correct symbols for elements let alone the formulas of compounds, but those papers were relatively scarce. The mean score on this part of the exam has been hovering around 7–8 for the last few years since teachers have been preparing students for this section more intentionally. Coupled with the more familiar reactions being tested recently, students have been able to attempt and complete a greater number of the choices. The most common reactions attempted on this question seemed to be (h), (e), and (g), with (a), (b), and (f) appearing more infrequently. Generally, if students received any points, it would be for the combustion reaction.

What were common student errors or omissions?

The most common error still seems to involve knowing and understanding the solubility rules enough to correctly write net ionic equations. Students either write the molecular form of a compound or go too far in the process and separate covalent compounds into "ions." Another common error was confusing heating and combustion. Many students classified heating as a reaction with oxygen instead of a simple decomposition. One of the biggest issues is students' inability or unwillingness to visualize the reaction and the medium in which the reaction takes place. A decomposition becomes a dissociation into ions because a student has not considered that a solid being heated is different from a solid dissolving in water. Finally, students seemingly understand simple redox reactions (such as zinc and a copper compound); however, the same students on another reaction will change the oxidation states of some products and not others. It is clear that there is intrinsic misunderstanding of oxidation-reduction as an electron transfer process.

Reaction (a):

- Incorrect formulas for potassium chlorate—most commonly KCl or $KMnO_4$
- Dissolving the solid into its constituent ions
- Creating chlorine gas
- Reacting with oxygen

Reaction (b):

- Incorrect formula for silver chloride
- Hydrochloric acid written in molecular form
- Products given ranged from synthesis of all elements to chlorine and hydrogen gas, rarely the correct complex ion

Reaction (c):

- Acetic acid written as a strong acid and barium hydroxide as a weak base
- Barium acetate written as an insoluble product
- Acetate ion written incorrectly
- Most common incorrect equation was $H^+ + OH^- \rightarrow H_2O$

Reaction (d):

- Ammonia written as ammonium (usually without the charge)
- Hydrofluoric acid written as a strong acid
- Ammonium hydroxide product written in molecular form
- Oxidation of fluoride ion to diatomic fluorine, with an accompanying reduction
- Some students recognized this as an acid/base reaction, and water was included as a product

Reaction (e):

- Zinc sulfate and copper(II) sulfate written as insoluble compounds
- Two oxidations, two reductions, or no oxidation or reduction

Reaction (f):

- Phosphine written incorrectly
- Products indicating a double-displacement reaction
- Reactants or products written as ions

Reaction (g):

- Complete molecular equation
- Nickel(II) hydroxide written as NiOH or $NiOH_2$
- Compounds of two anions and two cations
- Complex ion formation with incorrect charges

Reaction (h):

- Incorrect formula for hexane, most commonly C_6H_{12}
- Omitting oxygen as a reactant
- No reactants at all, just correct products for the combustion
- Very few errors on products: hydrogen gas, HC, and C_xH_y were sporadically included

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?

Because this question is changing its format in 2007, there are several key points that teachers need to keep in mind to prepare students to be successful on the equation question next year.

Both formats

Students must know and understand:

- Solubility rules
- That an element has to appear on both sides of the equation
- Molecular versus net ionic equations
- Difference between strong and weak acids
- Formulas and charges of common polyatomic ions
- Formulas of molecular compounds, including common organic compounds
- Conditions that favor the formation of complex ions
- Redox reactions as a transfer of electrons, where two species must change oxidation state
- Reaction dynamics associated with the reacting medium (aqueous versus nonaqueous)
- Distinction between heating and combusting

2007 format

Students must know and understand:

- How to balance chemical equations
- The process of chemical reactions well enough to answer questions relating to the reaction, including descriptive chemistry. Sample questions might be:

    Which substance is oxidized?

    What is the oxidation number of the element before and after the reaction?

What species acts as a Lewis base in the reaction? Explain.
What is the color of the solution before and after the reaction takes place?
Explain why a solution of equimolar acid and base in the reaction is basic (or acidic).
Identify the spectator ions in the reaction.
When one molecule of reactant *X* reacts, how many molecules of product *Y* are formed?

As a last note, general statements about reactions (such as all acid-base reactions produce water) have to be carefully contextualized.

Question 5

What was the intent of this question?

The intent of this laboratory question was to assess students' ability to use laboratory data to solve problems and to work in a wet laboratory situation. In parts (a), (b), and (c) students were to use given data to explain laboratory observations; in part (d) they were asked to demonstrate their understanding of the use of common laboratory glassware; part (e) revisited part (a). In part (a) students were given lab data and asked to identify compounds; in part (e) students had to design a laboratory procedure to distinguish between two compounds.

How well did students perform on this question?

This question produced a full range of responses. The mean score was 3.23 out of a possible 9 points. A substantial number of responses received scores of 1 and 2. Many students correctly answered parts (a) and (b). Answers to part (d) indicated that many students were not familiar with the use of common laboratory glassware. In the final section, water solubility and flame tests were the simple experiments correctly described by most students. Addition of an acid containing an anion that would combine with the calcium ion, forming a precipitate, or a two-step process of adding an acid to dissolve the compounds followed by the addition of a water-soluble salt containing an anion that would form a precipitate with calcium ion, received full credit. Some students developed extremely elaborate and usually incorrect procedures for identifying the compounds.

What were common student errors or omissions?

Part (a): A few students identified compounds other than those given in the question.

Part (b): The most common errors were identifying either Na_2SO_4 as a solid, or showing both Na_2SO_4 and $Mg(OH)_2$ as products without identifying $Mg(OH)_2$ as the precipitate asked for in the question.

Part (c): Although most students wrote acceptable chemical equations, many gave explanations that did not clearly identify CO_3^{2-} as the base. The most common misconception was that the Na^+ was responsible for the basic properties of the solution. Many students explained that Na_2CO_3 or Na_2SO_4 is basic because it is the salt of a strong base and a weak acid. This did not earn the second point.

Part (d): Although the question asked students to use specific glassware, on many responses other equipment was employed. Other responses used the buret, volumetric flask, and small dropper inappropriately. The buret was used as a graduated cylinder (solution was added to the 33 mL mark and then poured from the buret into the flask). Many confused dilution with titration and added an indicator during the process. The volumetric flask was incorrectly "completely filled"; many students did not know that it has a calibration line. The small dropper was used to deliver 33 mL of solution. Other misconceptions centered on the addition of specified volumes of both water and NaOH solution to yield 100 mL of solution. The dropper was used to add or remove NaOH solution to adjust the volume to the calibration line on the flask.

Part (e): The major error was the misconception that $CaCO_3$ is water soluble. This led to the premise that $CaCO_3$ forms Ca^{2+} and CO_3^{2-} in solution, which was used to describe conductivity or precipitation reactions and the effects of colligative properties such as boiling point elevation and freezing point depression. Some students who used solubility tests to identify the compounds neglected to identify the solvent as water; others confused solubility with chemical reactions that produce a precipitate. Some students who chose to describe flame tests misidentified or omitted the correct color.

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 certain that their students:

- Read questions carefully and use the given information to answer the question (e.g., "compounds … are KCl, Na_2CO_3, and $MgSO_4$" and "using a 50 mL buret, a 100 mL volumetric flask, … and a small dropper").
- Learn solubility rules and the charges of common ions.
- Clearly indicate the answer (e.g., if the question asks to identify the precipitate and a student writes down more than one product, the student must indicate which one is the precipitate).
- Understand basic safety procedures in the lab (e.g., identification by taste tests is not acceptable).
- Are actively involved in wet laboratory experiences to enhance their understanding of chemical concepts and to enable them to describe the use of common glassware and standard laboratory techniques.
- Have sufficient experience in the laboratory to identify experimental procedures used to identify compounds (e.g., solubility, flame tests, precipitation reactions, freezing and boiling points, and conductivity).
- Recognize the appropriate glassware for each laboratory task.
- Know how to write the net ionic chemical equations for precipitation reactions, or to identify which products form precipitates.
- Understand the acidic and basic properties of salts and recognize that memorization of the "rules" to identify a basic salt is insufficient to demonstrate understanding of the basic properties of a solution.
- Know how to use the correct number of significant figures read from laboratory measuring instruments.
- Are able to communicate a logical sequence of steps to describe an experiment designed to test a given problem.

Question 6

What was the intent of this question?

Two areas in the AP Chemistry curriculum were explored in this question: the role of intermolecular *vs.* intramolecular forces (parts (a), (b) and (c)), and the effect of catalysts on chemical reactions (part (d)). In part (a) students were asked to identify the intermolecular forces between glucose molecules in pure glucose (a)(i) and between cyclohexane molecules in pure cyclohexane (a)(ii). Part (b) asked them to account for the solubility of glucose in water and the relative insolubility of cyclohexane in the same solvent. The types of intermolecular and intramolecular forces cleaved in two different reactions had to be identified in part (c). For part (d) the question skipped to the topic of kinetics, and students were asked to identify the reaction coordinate graphs appropriate for a catalyzed and uncatalyzed version of the same reaction, and to explain the role of a catalyst in a reaction.

How well did students perform on this question?

This question produced a full range of responses, with many excellent scores and a significant number of zeros and 1s. The mean score was 4.04 out of a possible 9 points.

What were common student errors or omissions?

The overarching error in parts (a), (b), and (c) was the confusion concerning the meaning of <u>intra</u>molecular and <u>inter</u>molecular. Students could explain that they were talking about the interactions between two molecules, and then refer to it as an intramolecular attraction. Thousands of responses had descriptions of the covalent bonds between the H and O atoms within a molecule of water, and then referred to it as an intermolecular force.

Part (a): The confusion between intramolecular and intermolecular interactions was particularly obvious, as many answers focused on the nature of the C−C, C−O, or C−H bonds, rather than on the intermolecular interactions asked about. Discussions of covalent, sigma, and even pi interactions between the molecules were common. Since cyclohexane contains many H atoms, hydrogen bonding was commonly cited (incorrectly) as an intermolecular interaction between cyclohexane molecules.

Part (b): There was a great deal of confusion over what is meant by the adage “like dissolves like.” Many students made this type of argument: like dissolves like, and both water and glucose contain O and H atoms, so they are alike. Since cyclohexane has no oxygen atoms, it is not like water, and therefore isn’t water soluble. The argument could also take this form: both water and glucose are ionic but cyclohexane is covalent, and only ionic things dissolve in ionic solvents—like dissolves like. Another common mistake was to assume that the –OH functional groups on glucose react with the H^+ ions in water to form more water, making glucose soluble; since cyclohexane does not have OH groups, it stays together in water and does not dissolve. This confusion about glucose breaking up in water (and dissolving) while cyclohexane stays together (making it insoluble) was widespread. Many students assumed that for a material to *dissolve*, it must *dissociate*.

Part (c): Many of the errors seen for part (c) duplicated those seen in part (a), with confusion concerning the difference between intramolecular and intermolecular interactions being the dominant mistake. A distressing number of students thought that (an explosive mixture of) hydrogen and oxygen gases formed when water boiled (part (c)(ii)), and many students referred to the *ionic* bonds between O and H atoms within a water molecule.

Part (d): There was a surprising disconnect between a “lowered activation energy” and the effect that such a lowering has on reaction rate. Thousands of papers correctly indicated (in part (d)(ii)) that a catalyst lowered the activation energy for a given reaction but then proceeded to argue that the catalyst has no effect on the rate of the reaction, neither increases nor decreases the reaction rate, or does not get involved in the 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?

One important concept that is difficult to overemphasize: <u>intra</u>molecular means "within the molecule" and <u>inter</u>molecular means "between molecules." Covalent and ionic bonds are intramolecular interactions, while hydrogen bonds, dipole-dipole interactions, and London dispersion forces are intermolecular interactions. Many students considered hydrogen bonds to be any intramolecular bond with hydrogen at one end; C−H and O−H polar covalent bonds were often identified as hydrogen bonds. The difference between what happens when electrolytes dissociate (and dissolve) in water and when nonelectrolytes dissolve (without dissociating) should receive more attention in many classrooms. They have distinct meanings, yet many students assumed that *dissolve* and *dissociate* were synonyms.

Some final points:

- If the question asks "Indicate whether you agree or disagree with the statement in the box below," try to get your students to begin their answer with an "I agree" or "I disagree." Then, and only then, should they go on to their explanation. Many students wrote a great deal of prose but did not answer the question and did not receive credit for their response.
- If the question asks them to discuss <u>each</u> of two situations (as in part (c)(i)), encourage your students to address each situation explicitly. They should write the number and the letter of each section—"(c)(i) process 1," for example—as this helps ensure that the Reader will be able to see the answer and know to which question the answer should apply. Even skipping a line between processes helps clarify the answer for the Reader.
- Convince your students that they must be explicit in their answers. For example, in part (b), the question asked students to explain why glucose is soluble in water and why cyclohexane is not. Saying that "glucose is a polar molecule" does not imply anything about the polarity of water or the polarity of cyclohexane. The Reader cannot attempt to guess what the student meant; the answer has to be on the page.
- Answers to the questions should only appear in the lined part of the question booklet, not tucked between lines within the question. Answers written within the question are generally too brief to be correct and are often difficult (or impossible) to read.

Question 7

What was the intent of this question?

The intent of this question was to test students on their ability to draw Lewis structures, to recognize the hybridization and geometry of the Lewis structure drawn, and to predict the effect of a nonbonding pair of electrons on the bond angle of a species. Additionally, students were tested on their knowledge of expanded valence shell hybridization and geometry and on their ability to determine the oxidation number of an element in an ionic compound.

How well did students perform on this question?

This question produced a full range of responses. The mean score was 3.89 out of a possible 8 points. A substantial number of responses received the full 8 points. Students were generally able to draw a Lewis structure of some sort for parts (a)(i) and (b)(i). Often they were then able to do parts (a)(ii), (a)(iii), (b)(ii), and (b)(iii) correctly for the hybridization and geometry of the Lewis structure that was drawn. Most students were able to determine the oxidation number of S in $CsSF_5$. Many received points for the correct association of the geometry of the Lewis structure drawn and the corresponding geometry.

What were common student errors or omissions?

Parts (a)(i) and (b)(i): Some students did not know how to count valence electrons with a charged species so they did not earn points for the Lewis structures. It is interesting to note that a sample of students could do the Lewis structure for the expanded valence SF_5^- ion in part (b)(i) and not the SF_3^+ ion in part (a)(i).

Parts (a)(ii), (a)(iii), (b)(ii), and (b)(iii): A sample of students would know the geometry and not the hybridization of the species in both part (a) and part (b).

Part (a)(iv): A commonly missed point was for the prediction of the bond angle for the SF_3^+ ion with a supporting reason. Many predictions were in the wrong direction (picked equal to or larger than). A lot of students made a statement of fact that the bond angle for trigonal pyramidal was less than 109.5° (some of them even assigning numerical values such as 107° or 104°), which was not sufficient to earn the 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?

Teachers should make sure that their students:

- Learn how to count electrons for charged species.
- Are consistent in the representation of electron pairs—use either dots or dashes so that they do not represent more electrons than the number of valence electrons present in the Lewis structures drawn.
- Learn hybridization and the corresponding shapes.
- Learn the correct names of the shapes for expanded valence geometries.
- Learn the difference between bonding and nonbonding pairs.
- Use the correct vocabulary for unshared pairs (not referring to them as "unpaired electrons," "lone electrons," "extra pairs").
- Represent the bonding and not the complementary angle for a structure (often there was not a clear idea as to what the F–S–F angle represented).
- Use models so that they can see the shapes of species (either hands-on models or computer models).
- Understand hybridization in general terms (e.g., students should recognize that sp^4 hybrids do not exist).
- Know the effect of nonbonding electrons on the shape of a species.
- Know how to calculate oxidation number for an atom in a compound.
- Know that the geometry of a species represents the shape of the species that one would see if the species could be magnified. The use of three-dimensional models in teaching is helpful for students to understand the geometric shapes of species.

Question 8

What was the intent of this question?

The intent of this question was to test students on their ability to make predictions about the chemistry of a hypothetical element with atomic number 119. Students were asked to write the ground-state electron configuration of the valence shell, to predict and explain in terms of electron configuration whether Q would be a metal or a nonmetal, to state and explain in terms of electronic structure whether Q would have the largest or smallest atomic radius in its group, to give the most likely charge of the Q ion, to write a balanced equation for the reaction of Q with water, to write the formula for the compound formed between Q and the carbonate ion, and to predict and explain whether the compound would be soluble in water.

How well did students perform on this question?

This question produced a full range of responses. The mean score was 4.37 out of a possible 8 points. A substantial number of responses received the full 8 points. Students were generally able to determine that Q had one valence electron, identify the element as a metal, give the charge on the Q ion, and write the formula for its carbonate. Most students stated correctly that Q was the largest in its group. The majority of students earned at least 1 point on the equation for the reaction of Q with water, but many did not recognize the relationship to the reaction of water with the other alkali metals. The majority of students earned between 4 and 6 points on this question.

What were common student errors or omissions?

Part (a): The vast majority of students were able to give the correct electron configuration of Q as $8s^1$, but some wrote only $8s$, which did not earn the point. A number of other configurations were given, some of which were clearly a consequence of miscounting electrons. A surprising number of students gave the configuration $5s^2\ 5p^2$, having decided that element 119 was Sn, presumably confusing atomic mass for atomic number. Some students did not earn the point in part (a) because they wrote a Lewis dot diagram ($Q\cdot$) instead of an electron configuration. Some students did not write a correct electron configuration but were able to identify the element as an alkali metal.

Part (b): The most common error was to explain the metallic nature of Q in terms of its position in the periodic table (e.g., left side, to the left of the "stairs") rather than in terms of electron configuration. Some students identified Q as a nonmetal even though they placed it correctly in Group 1.

Part (c): Many students stated that Q would have the largest atomic radius in its group but explained this in terms of periodic trends rather than in terms of electronic structure. Some students discussed the decrease in radius across the periodic table, apparently confusing group and period. Others invoked the concept of shielding but failed to describe the origin of this shielding (intervening shells of electrons) and so did not earn this point.

Part (d): Some students gave incorrect charges, including -1, and some simply said "positive." A small number of individuals who gave incorrect electron configurations earned the point in part (d) if the charge they proposed was consistent with the configuration in part (a).

Part (e): The most common errors were failing to balance the equation, putting a positive charge on element Q as a reactant, and/or showing H^+ as a product.

Part (f)(i): Students generally had the formula for the carbonate correct, although some formulas were not consistent with the charge given in part (d). Students sometimes left ionic charges on the ions in a compound (e.g., ${Q^+}_2{CO_3}^{2-}$ or $Q_2{CO_3}^{2-}$).

Part (f)(ii): It was often difficult to tell whether a student was referring to the solubility of Q_2CO_3 or to the solubility of the metal itself; students would often argue that it is soluble because all alkali metals are soluble. Some answers proposed a reaction of the carbonate with water to account for the dissolving process and others referred to the polarity of Q_2CO_3 and explained its solubility in terms of "like dissolves like."

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:

- Answer the question written (e.g., "Explain in terms of electron configuration," and "Write a balanced equation").
- Use chemical terms in a precise manner (e.g., "group" vs. "period," or "orbital" vs. "energy level").
- Omit charges from final formulas of ionic compounds.
- Are consistent in their answers from one part of the question to the next (e.g., Q^- and Q_2CO_3).
- Are very familiar with solubility rules.
- Know that the correct name for Group 1 is the alkali metals, not alkaline metals or alkali earth metals.
- Know that the families to the left of the transition metals are also metals.
- Understand that stating a trend does not constitute giving an explanation.
- Know that dissolving an ionic compound implies the dissociation into ions rather than reaction of these ions with water to give other products.