Student Performance Q&A:

2010 AP® Chemistry Free-Response Questions

The following comments on the 2010 free-response questions for AP® Chemistry were written by the Chief Reader, Larry Funck of Wheaton College in Illinois. 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 assessed students' knowledge and skills concerning the concept of the equilibria that exist with slightly soluble salts. Parts of the question were mathematical and parts were conceptual in nature. In parts (a) and (b) students were required to write the correct K_{sp} expression of AgBr and then calculate the $[Ag^+]$ using the K_{sp} provided. In part (c) students had to recognize that the $[Ag^+]$ remains constant in a saturated solution after the addition of water when solid AgBr remains after equilibrium is reestablished. Part (d) required students to calculate the minimum volume of water necessary to completely dissolve 5.0 grams of AgBr. Students had to convert grams to moles and then divide this answer by the molarity of the silver ion calculated in part (b). In part (e) students were expected to recognize that a precipitate of AgBr would occur. First, students had to calculate the concentration of Ag^+ and Br^- ions present when $AgNO_3$ and NaBr solutions were mixed, solve for Q, and, finally, compare the Q value to the given K_{sp}. Part (f)(i) required students to write a balanced chemical equation that represents the formation of silver iodide when an aqueous solution of sodium iodide is mixed with solid silver bromide. Part (f)(ii) asked students to draw the conclusion that AgBr had a greater K_{sp} than AgI based on the laboratory evidence given.

How well did students perform on this question?

Overall students did reasonably well when answering this question. The mean score was 3.66 out of 10 possible points, and the distribution showed a single maximum with the modal score between 2 and 3. Some 13 percent of students either earned no points with their response or failed to address the question, while 2 percent achieved a score of 10.

Students were generally successful on part (a) and part (b), earning 1 point for the correct K_{sp} expression and 1 point for the correct silver ion concentration. In part (a) a subset of students included the solid [AgBr] in the K_{sp} expression. In part (b) a subset correctly calculated $[Ag^+]$ but then used the given volume to calculate an incorrect answer.

Many students recognized the system as an equilibrium system and earned 1 point in part (c) for indicating that the $[Ag^+]$ concentration remained the same after the addition of distilled water. However, it was common for students to conclude that there was less $[Ag^+]$ owing to the dilution by additional water.

In part (d) a majority received 1 point for the calculation of moles of AgBr. However, a much smaller population of students successfully calculated the volume of water necessary to completely dissolve the 5.0 grams of silver bromide.

Part (e) was challenging for students. Many students earned 1 point for stating that a cream-colored precipitate of silver bromide would be observed. However, students often ignored the fact that the system was an equilibrium system and chose a limiting reagent argument or based their conclusion on solubility rules. Many students also earned 1 point for comparing Q to K_{sp}. The least likely point to be earned was the one assigned for dilution of the silver ion and the bromide ion.

The majority of students earned 1 point in part (f)(i) for writing the correct chemical equation. The point in part (f)(ii) was a bit more difficult for students to earn. Identifying that the K_{sp} of AgBr is greater than the K_{sp} of AgI, with a valid explanation, was required. Often students concluded incorrectly that AgI had the greater K_{sp} because the precipitate was yellow at the end of the experiment.

What were common student errors or omissions?

Part (a):

- Including [AgBr] in the denominator
- Writing $K_{sp} = [AgBr]$
- Failing to include charges on the silver ion and the bromide ion

Part (b):

- Dividing molarity by 50.0 mL (or 0.050 L) and identifying that value as the $[Ag^+]$
- Multiplying by 50.0 mL (or 0.050 L) and identifying that value as the $[Ag^+]$
- Setting up an equilibrium table (reaction, initial, change and equilibrium values) and assigning a value of 1.0 *M*, 0.05 *M* or 50 *M* to the solid AgBr
- Using a K_{sp} value of 5.0×10^{-3} instead of the given K_{sp} of 5.0×10^{-13}
- Using too many significant figures
- $[Ag^+]$ = moles instead of moles per liter

Part (c):

- Ignoring the fact that AgBr solid is present even after the addition of water and concluding that the additional water would dilute the $[Ag^+]$
- Stating the idea that as water is added to the system more silver ions go into solution, thereby increasing the $[Ag^+]$, ignoring the fact that equilibrium was reestablished

- Stating that $[Ag^+]$ remains the same but including incorrect statements in the explanation, such as that AgBr is at equilibrium and will stop dissolving (Solids are not part of the K_{sp} expression so the water makes no difference.)
- Not recognizing that adding water does not change molarity because water is not included in the equilibrium expression. Students needed to be specific and state that the volume change does not alter the $[Ag^+]$ because the solution was saturated and at equilibrium.
- Incorrectly stating that the amount of Ag^+ ions would remain unchanged

Part (d):

- Using 22.4 $L\ mol^{-1}$ or $PV = nRT$ to find volume in this nongaseous system
- Inability to calculate the correct volume even when the setup was correct (Volume was in the denominator.)
- Assuming the answer was in mL and dividing the correct volume by 1,000
- Using the 50.0 mL from part (b) or part (c)
- Rounding moles of AgBr to one significant figure and using this number to calculate volume, causing an 11 percent error
- Reporting too many significant figures

Part (e):

- Not calculating the dilution of the two ions in solution
- Calculating moles of each ion and using the moles to calculate Q
- Using a limiting reactant approach only to calculate moles of AgBr
- Calculating [AgBr] and not the ions after dilution
- Difficulty in interpreting negative exponents as being larger or smaller when comparing Q to K_{sp} (e.g., $1.0 \times 10^{-8} < 5.0 \times 10^{-13}$)

Part (f)(i):

- Writing only a net ionic equation for the precipitation of AgI, ignoring the dissolution of AgBr
- Not balancing both mass and charge
- Indicating charges on solid compounds (e.g., $Ag^+Br^- + Na^+I^- \rightarrow Ag^+I^- + Na^+NO_3^-$)

Part (f)(ii):

- Justifying the greater K_{sp} of AgBr using periodic trends, size of the anions, reduction potentials, activity series, electronegativity, molar mass, number of electrons and number of electron shells
- Concluding that AgI had a higher K_{sp} because the color in the solution favored this substance

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?

Suggestions for teachers:

- Provide opportunities for students to write explanations and revise their writing. Students should have a general control of language to clearly articulate their understanding of chemical concepts.
- Emphasize that observations are statements. A chemical equation does not replace the observation.
- Be sure that all students are equipped with a working calculator for the exam.
- Never accept calculated answers without clearly organized work being shown.
- Work through calculations, making sure that students understand why each step of the calculation is reasonable and legitimate.
- Stress that penmanship and clarity are important in communication.

Suggestions for students:

- Do not continue writing further explanations after the question is answered.
- Watch for careless errors; be sure that numbers used for calculations are the numbers given in the question, paying close attention to exponents.
- Make a clear distinction between moles and the symbol for molarity, M, and understand the meaning of the brackets used for molarity $[Ag^+]$.
- Show all work for calculations to receive credit.
- Learn the conditions under which $PV = nRT$ and 22.4 L mol^{-1} are applicable, and when they are not.
- Review and consistently apply rules for significant figures, and avoid rounding off before the final answer.
- Be sure to remove all random charges from neutral compounds (e.g., Ag^+Br^-).
- Remember that small capital letters are not acceptable for the second letter in a chemical symbol (e.g., BR instead of Br).

Question 2

What was the intent of this question?

This question assessed students' knowledge and skills pertaining to a laboratory experience that involved preparing a solution in a coffee-cup calorimeter and measuring the results. Parts of the question were mathematical and parts were conceptual in nature. In part (a) students were required to examine a temperature–time graph and use graph-reading skills to determine the temperature change that occurred as a solution of urea and water formed. Part (b) required classification of the process as either endothermic or exothermic based on the change in temperature. In parts (c)(i) and (c)(ii) students had to calculate the heat of dissolution of urea with the equation $q = mc\Delta T$ and then convert that calculated energy into a molar enthalpy. Part (d) required students to calculate a molar entropy of solution with the equation $\Delta G = \Delta H - T\Delta S$ given a table of accepted values for the

ΔH°_{soln} and ΔG°_{soln} of the solute (urea). Part (e) supplied a percent error from a student experiment and required calculation of the experimental value obtained from that experiment. Part (f) involved an error analysis whereby students needed to predict the effect on ΔH°_{soln} of using a sample of solute at a colder temperature and then justify their prediction.

How well did students perform on this question?

The mean score was 4.26 out of a possible 10 points. There was a single maximum in the distribution, the modal score being 4, with 17 percent of the students achieving that score. Some 12 percent of the students earned no points or failed to address the question, and only 1 percent achieved the maximum score of 10. Students generally answered all parts of the question, with most of the points earned in part (a) by reading a graph and in part (e) by knowing how to calculate an experimental value when given a percent error and an accepted value. There was more difficulty in the parts of the problem that required energy flow and error analysis and justification.

What were common student errors or omissions?

In part (a) many students either did not read accurate temperatures from the graph or did not record readings to the correct number of significant figures (temperatures reported for the observed 21.80°C on the graph varied considerably, with common values of 21.0, 21.7, 21.9, 22.2, 22.8 and 25.0). Even when the precise values were recorded, students often failed to calculate a ΔT for a correct response or made mistakes in subtraction of final and initial temperatures. Another mistake was to confuse the change in temperature, ΔT, in Celsius degrees with an actual temperature value on the Kelvin scale (i.e., $\Delta T = 3.2°\text{C} = 276.2\text{ K}$).

In part (b) the question began with “According to the data”; therefore students had to tie their response to the observation. However, many did not make reference to the given data. Many students correctly stated that the reaction is endothermic but did not earn credit because they did not refer to the graph or the concept of heat being absorbed by the system. Responses often merely defined an endothermic process. There was much confusion about what constituted the system and what constituted the surroundings. A great number of students ignored the labels on the graph and interpreted the diagram as a reaction energy diagram for an exothermic process, with the reactants being higher in energy than the products.

In part (c)(i) the most common mistake was to substitute incorrect masses into the equation $q = mc\Delta T$. Also, incorrect algebraic manipulation often yielded an equation like this: $q = \dfrac{mc}{\Delta T}$. Some students misinterpreted the m in the equation as molality, or even moles. Even though the question itself stated that the specific heat capacity was that of the combined solute and solvent, students often substituted only the mass of the solute urea or only the mass of the solvent water. Quite a few used an incorrect temperature, such as 298 K or 25°C, instead of the ΔT from part (a). Many students reported a negative heat of dissolution, even if they had previously classified the process as endothermic.

In part (c)(ii) units were often incorrect, and, as in previous years, some students still had difficulty converting kJ to J. If J was calculated instead of kJ, students did not earn credit if the units were omitted. Many students did not carry the answer from part (c)(i) for substitution into the calculation of molar enthalpy. The molar mass of urea was often incorrectly calculated, the number of moles calculated was sometimes moles of water, and even total moles showed up in the solution to the problem. Some students even used grams instead of moles to calculate an enthalpy change per gram rather than an enthalpy change per mole. Students had quite a lot of trouble with signs.

There also seemed to be confusion of specific heat with heat capacity, as an equation commonly selected was $C_p = \frac{\Delta H}{T}$, with substitution of any two variables. Some students tried to calculate the answer with the equation $\Delta H^\circ_{rxn} = \Sigma\Delta H^\circ_{products} - \Sigma\Delta H^\circ_{reactants}$. A common error in both parts (c)(i) and (c)(ii) included responses with too many or too few significant figures.

In part (d) many students who selected the correct equation, $\Delta G = \Delta H - T\Delta S$, struggled with the algebraic manipulation necessary to isolate ΔS. Students would incorrectly substitute a temperature or a temperature change from the experiment for T (21.8, 25 or 3.2 instead of 298). Even with proper substitution of values, the answer label $\frac{\text{kJ}}{\text{mol K}}$ often omitted K in the denominator, resulting in loss of credit.

In part (e) the majority of students were able to calculate the experimental value given the accepted value and the percent error. Some confused accepted and experimental, resulting in $\frac{14 - x}{x} = 11\%$, and others added the error to the accepted value to obtain the experimental value. Students often ignored the data table in parts (d), (e) and (f).

In part (f) many students did not predict the direction of change in ΔH or state the justification for the change. Some used $H^\circ_{initial}$ and H°_{final} to explain why ΔH would change with a temperature change. A significant number of students did not make any reference to a difference in the ΔT. Justifications often centered on the urea being colder, but not on the fact that a larger temperature difference caused the increase in the calculated ΔH. Some who made a good argument never mentioned ΔH. Some students who calculated a negative ΔH in part (c) tried to connect their response to this incorrect negative result, when in essence supplying the accepted value in the given table reset ΔH. Many responses attempted to make a kinetic energy argument, claiming that the reaction would happen more slowly or would not have enough energy to go to completion.

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?

Suggestions for teachers:

- Provide frequent practice for students in graph construction, reading skills and interpretation skills.
- Laboratory investigations should require analysis of temperature–time graphs and should connect the temperature change with classification of processes as exothermic and endothermic.
- Instruct students to answer the question posed before them.

Suggestions for students:

- Know how a coffee-cup calorimeter works and the meaning of “heat of dissolution.” Too many students ignored the observed change in temperature or did not relate the given specific heat of the solution to both solute and solvent.
- When asked to provide an answer “according to the data,” use the data to answer the question instead of providing a memorized definition.

- To earn credit for showing work, a setup must be provided. This specifically means that all the numbers have to be substituted into the selected equation. If the units requested are kJ, then do not give J and vice-versa.
- When algebra is applied, always ask the question, “Does this make sense?” This becomes quite important, especially when the expectation is to define system and surroundings and flow of energy between them. In this particular instance, students should have enough conceptual knowledge to change a negative sign to a positive when it is apparent that an endothermic process is occurring.
- Be careful of language when responses require justification. A temperature can be for the solute, the solvent or the solution; it can be initial or final and is quite different from a change in temperature. Unclear language will not lead to earned credit.

Question 3

What was the intent of this question?

This question assessed students’ understanding of stoichiometry, the relationship among variables of state for gases, and reaction kinetics. Part (a)(i) required students to determine the moles of Cl^- ion present in a given volume of a solution of given concentration. Part (a)(ii) required students to determine the moles of $Cl_2(g)$ formed by using the balanced equation and then to determine the volume of this gas at the stated nonstandard conditions of temperature and pressure. Part (b) asked students to use given experimental data to determine the order of the reaction with respect to two of the reactants. Part (c) required students to use these orders, together with additional information, to write the rate law for the reaction and to determine the value and units of the rate constant. Part (d) asked students to assess the likelihood of the reaction occurring in a single elementary step.

How well did students perform on this question?

Student performance was generally fairly good, with a mean score of 4.05 out of 9 possible points. The distribution of scores was relatively flat, with a standard deviation of 2.80. Some 3 percent of students earned the top score of 9. Generally the question seemed to effectively discriminate among students with varying levels of understanding of these topics.

Because the question assessed three different topics (stoichiometry, gas laws, reaction kinetics), many responses earned all available points on one or two topics and failed to earn any credit on other topics.
The 5 points available in parts (a)(i), (a)(ii), (b)(i) and (b)(ii) were the most accessible to students, with most responses earning all the points. Students generally had difficulty using the information to write a complete and well-formed rate law in part (c)(i) and to perform the necessary calculation to evaluate the rate constant and unit in part (c)(ii). The point available in part (d) was least frequently earned. Although most students correctly stated that the reaction is unlikely to occur in a single elementary step, the justifications were often too vague and general to earn credit.

What were common student errors or omissions?

Part (a)(i):

- Failing to use the correct relationship among concentration, volume and moles
- Multiplying by the stoichiometric coefficient of Cl^- in the balanced equation (4)

- Failing to differentiate between Cl^-, NaCl and Cl_2 as species

Part (a)(ii):

- Failing to use the stoichiometry of the given reaction equation to determine moles of Cl_2, or equating n_{Cl_2} and n_{Cl^-}
- Multiplying the moles of Cl_2 by the standard molar volume of a gas at STP (22.4 L) with no correction for nonstandard temperature and pressure

Part (b):

- Poorly understanding the relationship between reactant concentration and reaction rate
- Failing to show sufficient justification, either narrative or algebraic, for (correct) orders
- Using incorrect calculations, e.g., $3^x = 9 \Rightarrow x = 3$

Part (c)(i):

- Failing to write a well-formed rate law consistent with the orders obtained in part (b):
    - Omitting "Rate =" from the rate law and giving an expression rather than an equation
    - Omitting the rate constant from the rate law
    - Failing to read the full question, often omitting the factor "$[H^+]^3$" from the rate law

Part (c)(ii):

- Incorrectly calculating the numerical value of the rate constant, *k*
- Using incorrect units for the rate constant (Many students do not understand the relationship between the order of the reaction and the units of the rate constant.)
- Omitting units for the rate constant (The rate constant, *k*, is confused with the equilibrium constant, *K*, which is unitless.)

Part (d):

- Stating vaguely that the reaction was "too complex" to occur in a single step, that "too many things reacted," or that reactions with high orders were uncommon
- Stating that an oxidation-reduction reaction required two steps (an oxidation step and a reduction step) and therefore could not occur in one elementary step
- Claiming that different reaction orders for each reactant implied that the reaction must occur in a series of steps
- Confusing the number of reactants (3) and the number of reacting particles (13) in the balanced equation
- Confusing "order" and "molecularity" of reactions

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?

Suggestions for teachers:

- Emphasize the independence of ions in aqueous solution — that one ion of a dissolved species may (and frequently does) react independently of the other (spectator) ion.
- Be sure that students understand the form of a rate law and the distinction between the reaction rate, the order(s) with respect to each reactant, and the rate constant.
- Review determination of moles of a species from mass and formula mass, from volume and concentration of a solution, and from volume, pressure and temperature of a gas.
- Review simple stoichiometric relationships among moles of reactants and products, even when stoichiometry is not the focus of the problem.
- Emphasize the consistency of units — that reaction rate in solution is always expressed in units of $M\,s^{-1}$ (or other unit of time^{-1}) and that units for the rate constant must be consistent with the overall reaction order.
- Require students to interpret the rate law in terms of plausible reaction mechanisms and to discuss molecularity and the collision model of chemical reactions.

Suggestions for students:

- Practice problems that require the determination of reaction orders from initial-rate data.
- Practice simple arithmetic operations such as multiplication and division with numbers expressed in scientific notation on the calculator. Review order of operations and estimation of results. Work problems through to the final answer.

Question 4

What was the intent of this question?

This question assessed students' ability to communicate their knowledge of chemical processes. Important skills tested included writing chemical formulas for substances and balancing equations. Additional aspects of the problem evaluated general understanding of chemical concepts presented to students in both the classroom and the laboratory.

How well did students perform on this question?

The mean score was 8.99 out of 15 possible points. Students displayed a wide range of knowledge and skills in their responses to this question. The scores covered the entire scale and had a modal score of 13, with 11 percent of the students achieving that score. Some 7 percent of the responses earned a score of 15, and only 2 percent failed to address the question at all.

What were common student errors or omissions?

Part (a):

- Writing strong acids and strong bases as un-ionized species
- Using incorrect formulas for KOH and HNO_3

- Providing incorrect products of an acid base reaction
- Writing complete balanced equations for net ionic equations
- Writing complete ionic equations rather than net ionic equations
- Using molarities as reaction coefficients to balance equations
- Not being aware that "x is titrated with y" means that y is what is in the buret
- Not realizing that pH continues to change beyond the endpoint
- Leaving spectator ions in the final equation
- Writing in miscellaneous charges on the reaction species
- Indicating that the solution is clear, green, bluish green, greenish yellow and so on rather than the yellow solution at the endpoint
- Some common mistakes:
  $H + OH \rightarrow H_2O$
  $KOH + HNO_3 \rightarrow H_2O + KNO_3$
  $3\ KOH + H_3N \rightarrow K_3N + 3\ H_2O$
  $KOH + HNO \rightarrow KNO + H_2O$
  $KOH + HNO_2 \rightarrow KNO_2 + H_2O$
  $2\ KOH + H_2NO_3 \rightarrow 2\ KNO_3 + H_2O$
  $KOH + HN \rightarrow H_2O + KN$

Part (b):

- Not knowing the nomenclature of alkanes (Many nonsense formulas were used for propane; propane was represented as methane, ethane, butane, cyclohexane or many combinations that made no sense at all.)
- Not recognizing that CO_2 bubbled through water forms a dilute acidic solution
- Not reducing the stoichiometric coefficients to lowest whole numbers
- Giving such responses as:
    - Acidic because CO_2 removes H^+ from water.
    - Basic because H_2O reacts with CO_2 to form $HCO_2^+ + OH^-$.
    - Neutral because water is neutral or H_2CO_3 forms and immediately dissociates to H_2O and CO_2.
    - Neutral because water or carbon dioxide are not acids or bases.
    - Basic because CO_2 is a conjugate base.

Part (c):

- Using the incorrect formula for hydrogen peroxide
- Using oxygen gas as a reactant for a reaction that is heated (decomposition)
- Writing oxidation numbers above the formulas in the box

- Adding miscellaneous reactants as reactants, such as CO, manganese compounds and phosphorus compounds
- Confusing oxidation number with reducing agent/oxidizing agent
- Writing O_2^{2-} and not taking it further to O^- (–1 for each oxygen)
- Giving change in oxidation number rather than the oxidation number in the one substance specified in the question
- Common mistakes:
  $2\ H_2O_5 \rightarrow 2\ H_2 + 5\ O_2$
  $H_2O_4 \rightarrow H_2 + 2\ O_2$
  $2\ HO_2 \rightarrow H_2 + 2\ O_2$
  $H_4O_2 \rightarrow 2\ H_2 + O_2$
  $H_2O_5 \rightarrow H_2O$
  $H_2O_2 \rightarrow H_2 + O_2$
  $2\ H^+ + O_2^{2-} \rightarrow H_2 + O_2$

All parts:

- Writing miscellaneous charges over formulas in the box
- Writing several reactions in the box (Only the last equation in the box is scored.)
- Using incorrect nomenclature

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?

Suggestions for teachers:

- Remind students that the answer box should contain only the final, balanced chemical equation. Emphasize that the box should not contain oxidation numbers, scratch work, any other extraneous charges or numbers, or extra equations.
- Do titrations in the lab in both directions. Titrate an acid with a base and a base with an acid. This illustrates the colors at the endpoint.
- Use indicators in the lab other than phenolphthalein. Do labs or demonstrations that illustrate the color change for the common indicators used in AP Chemistry labs.
- Do a combustion lab or demonstration.
- Bubble CO_2 into water and check the pH of the resulting solution. Do the same with O_2 and see the difference.
- Decompose hydrogen peroxide and use a wood splint to see what happens when you put that splint into the resulting test tube. You get oxygen gas. Produce hydrogen gas and see what a wood splint will do in that test tube. Note the differences. Then have students write and balance the equations for those reactions.
- Have students write equations for the reactions in the demonstrations that you do. Students remember what they see and do better than what they hear.

Suggestions for students:

- Practice not only balancing equations stoichiometrically but also incorporating charge balance simultaneously.
- Understand the significance of chemical nomenclature when writing chemical formulas for molecules, atoms and ions in solution. Consider the following equations: $OH^- + H^+ \rightarrow H_2O$ and $KOH + HNO_3 \rightarrow KNO_3 + H_2O$. The first is correct and the second is incorrect because it does not recognize that KOH, HNO_3 and KNO_3 are ionized in water.
- Become very familiar with the list of common strong acids and strong bases and know that everything else is a weak acid or base. Many students indicated that HNO_3 was a weak acid. Many students indicated that nitric acid was HNO_2. These misconceptions led to points lost in part (a)(i).
- Know the names and formulas of the first 10 alkanes. Know the difference between alkanes and organic compounds with functional groups, such as alcohols, carboxylic acids, ketones and ethers.
- Do not confuse a decomposition reaction with an oxidation reaction or write O_2 as a reactant in the decomposition reaction.
- Learn the names and symbols of the common elements used (e.g., the symbol for potassium is K, not P).
- Cancel out common species that are present in both the reactants and the products.
- Reduce the stoichiometric coefficients to lowest whole numbers. Multiply fractional coefficients for lowest whole numbers as well.
- Remember that a correct answer without a reason usually receives no credit. When an explanation is requested, write a reason for the answer given.

Question 5

What was the intent of this question?

This question asked students to draw a correct Lewis electron-dot diagram for ethyne (C_2H_2) in part (a). In part (b) students were asked to compare the $C-C$ bond lengths in three given Lewis diagrams and the fourth diagram drawn for part (a). In part (c) students were given a Lewis diagram for ethanoic (acetic) acid and asked to describe the geometry around each C atom. In part (e) students were required to identify one of the given (or drawn) Lewis diagrams that represent a nonpolar molecule and to justify why it is nonpolar. Parts (d) and (f) explored students' understanding of intermolecular forces: Part (d) explored students' understanding of the interactions that are broken during vaporization, and part (f) probed students' understanding of the factors involved when a solute dissolves in a solvent.

How well did students perform on this question?

The mean score was 4.09 out of 8 possible points. The distribution was bimodal, with one maximum between 5 and 6 and the other at a score of 0. The question was well scaffolded; most students earned opening points, but few were able to earn points in part (e) or in part (f). Only 4 percent earned a top score of 8.

What were common student errors or omissions?

In part (a) a surprising number of students drew incorrect structures (with a C–C single bond for C_2H_2, and lots of lone pairs, even on bonded hydrogens), and a significant number drew the correct diagram for ethene, C_2H_4, not ethyne. A large percentage of the Lewis diagrams were not written in the box provided, and there were numerous cases of multiple diagrams with no indication of which was the student's final answer. Some students misinterpreted the formula C_2H_2 to imply a molecular skeleton of C–C–H–H.

In part (b) some students drew a correct Lewis diagram for ethyne but did not recognize that the triple bond, C≡C, was stronger than the single bond, C–C. Some drew incorrect Lewis diagrams for ethyne but then correctly said that ethyne had a triple bond, apparently recognizing the meaning of the "yne" suffix but not knowing how to draw the Lewis diagram. The errors in parts (a) and (b) were not that common, however, as most students did these parts correctly.

There were no apparent patterns to the wrong answers in part (c), and students generally were able to look at a Lewis diagram and understand the geometry of the atoms bonded to it. Some students gave only the hybridization of the central carbon atoms, sp^2 and sp^3, not the resulting geometry, as asked for in the question.

The common error in part (d) occurred when students confused *vaporization* (the process of boiling) with *combustion*. This led to essays explaining which intramolecular bonds would break (the C–C and the C–H) and which would not break (the C–O and the O–H); other discussions about which intramolecular bonds would break and which would not were also common. A significant number of students did think the statement was true, and a depressingly large number thought the statement was false because energy is released when bonds are broken. Confusion continues over whether a "hydrogen bond" is the covalent O–H bond within an ethanol molecule or an intermolecular interaction between molecules; numerous responses started with a phrase such as "ethanol contains a hydrogen bond," suggesting a reference to the O–H covalent bond in ethanol. This confusion also appeared in many answers to part (f). Merely stating that "boiling is just a phase change" does not address what the added energy is doing.

Part (e) was difficult for students, as most answers were unacceptably vague about what makes a molecule nonpolar. Phrases such as "the bonds cancel," "the charges cancel," "the carbons are surrounded by only hydrogens," there is "equal pull," or "it isn't lopsided" did not reach the standard of "the symmetric structure of ethyne [or ethane] causes the C–H bond dipoles to cancel." Stating that "ethyne is nonpolar because it has no net dipole" is merely a definition of "nonpolar" and does not refer to what it is about ethyne that causes it to be nonpolar. Other common mistakes included statements such as "since C–H bond are nonpolar, ethyne [or ethane] must be nonpolar" and "it must be nonpolar because the Lewis structure is balanced." Nonpolarity was often explained by a statement such as "ethyne had only covalent bonds," "there are no lone pairs," or "all electrons are paired."

The majority of students answered part (f) by categorizing ethanol and ethanethiol as "polar" and "nonpolar," respectively; putting water into the "polar" category; and then saying "like dissolves like," so ethanol is completely soluble in water but ethanethiol is not. This answer does not address the intermolecular forces involved in a solution; few students discussed that the hydrogen-bonding capabilities of both ethanol and water mean that hydrogen bonds (or dipole–dipole interactions) form *between* water and ethanol in the solution.

Other commonly seen misconceptions:

- Ethanethiol is not soluble in water because the intermolecular interactions among ethanethiol molecules are so strong that water cannot break in.
- Ethanethiol is insoluble because sulfur (or sulfides) is insoluble.
- Water has the power to “break up” or “dissociate” the ethanol but not the sturdier ethanethiol.
- The OH^- ion on ethanol reacts with the H^+ ion in water to form H_2O.

Finally, and most important, many students, as in part (d), thought the hydrogen bond was the O–H covalent bond within the ethanol (or the water).

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?

It is impossible to overemphasize the importance of writing precisely. Vague and unclear answers often made it impossible for AP Exam Readers to determine whether the student understood the chemistry. Clear, precise and succinct prose does not come naturally; we all must work on it. For example, statements such as “ethanol forms hydrogen bonds between the oxygen and hydrogen atoms,” “water breaks up ethanol,” or “when ethanol boils the attractions break” left Readers wondering whether intermolecular or intramolecular interactions were being considered. Numerous students referred to “atoms” as “molecules” and vice versa, often to the student’s detriment.

Suggestions for teachers:

- Do not let your students get away with sloppy or imprecise prose. For example, “balanced” is not acceptable as a substitute for “the individual bond dipoles balance.”
- Intramolecular and intermolecular interactions are always difficult for students to distinguish or describe, and this year’s AP Chemistry Exam showed that the confusion continues. Work with students to help them understand these concepts.

Suggestions for students:

- Be sure to label each response; this is especially true when choosing to answer the questions out of order.
- Remember that “like dissolves like” is not a “rule,” a “commandment” or an “explanation.” It is an aphorism that has become an overworked cliché; it does not explain anything, and it can distract from an understanding of the actual intermolecular interactions between a solute and a solvent.

Question 6

What was the intent of this question?

This question started with two parts on atomic structure and then dealt mainly with matters of electrochemistry. In part (a) students were asked to complete the electron configuration for a d-block ion. In part (b) students were asked to compare the ionization energy of this ion with the corresponding neutral atom. The rest of the question dealt with a specific redox reaction and a galvanic cell based on this reaction. In part (c) students were asked to identify the species that is oxidized. In part (d) they were asked to describe what happens in the salt bridge as the cell operates. In part (e) students were asked to calculate $E°$ for the cell. In part (f) students were required to indicate the sign of $\Delta G°$ for the cell reaction and to justify their answer. In part (g) they were asked to predict the effect on E_{cell} if the concentration of one of the components in the cell reaction is reduced.

How well did students perform on this question?

Student performance on this question was fair. The mean score was 3.43 out of a possible 9 points. The distribution was bimodal, with maxima at scores of 1 and 4. Only 3 percent failed to address the question, but only 1 percent earned the top score of 9. Students had difficulty with the atomic structure items but did relatively well on the electrochemistry-related questions.

In part (a) most students could not complete the correct electron configuration for Zn^{2+}. In part (b) most students could identify the positive ion as having the higher ionization energy but then could not provide a satisfactory justification for this choice. In part (c) most students could identify Al as the species oxidized. In part (d) some students could indicate the direction of flow of NO_3^- and K^+ in the salt bridge. In part (e) many students could correctly calculate $E°$. In part (f) many could identify $\Delta G°$ as having a negative value and justified this choice based either on the sign of $E°$ or on the cell reaction being spontaneous. In part (g) only some students could correctly provide a Nernst equation or a change in ΔG analysis to determine that the E_{cell} increases.

What were common student errors or omissions?

In part (a) the configuration for a Ni atom was the most common incorrect response. In part (b) many students incorrectly justified their answer by restating the answer, referring to periodic trends or making statements about shell or subshell stability. Many students also failed to address charge attraction/repulsion factors in their justification.

In part (c) most students gave the correct answer. In part (d) some students discussed the role of the salt bridge in maintaining solution charge neutrality without giving any specifics about what happens in the salt bridge. Some students had electrons moving through the salt bridge, and some had K^+ and/or NO_3^- moving in the wrong direction. Some students stated that K^+ and/or NO_3^- do move but failed to indicate in what direction.

In calculating $E°$ in part (e), some students made arithmetic mistakes — most often mistakes in handling negative signs. Some students multiplied the electrode potentials by the coefficients in the chemical equation. In part (f) there some students made a sign error when using the equation $\Delta G° = -nFE°$.

In part (g), if using the Nernst Equation to find the effect of lowered $[Al^{3+}]$ on cell potential, some students made a sign error somewhere in what was a multistep analysis. Some students treated Al^{3+} as a reactant, not as a product, in this reaction. Also, some students failed to recognize that although E°_{cell} is fixed for a given reaction, the actual E_{cell} does change with changing concentration.

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 more practice in finding the electron configuration of *d*-block ions.
- Help students understand that referencing a periodic trend or identifying a filled shell or subshell does not constitute an *explanation* of atomic property differences. It is the underlying physical principles of charge attractions and replusions, often described using effective nuclear charge, that are responsible for these property trends.
- Give students more practice performing effect-of-change analyses. This includes both using the mathematical equations common to thermodynamics and electrochemistry and doing a qualitative shift (similar to Le Châtelier’s Principle) analysis.