Student Performance Q&A:

2002 AP® Chemistry Free-Response Questions

The following comments are provided by the Chief Reader regarding the 2002 free-response questions for AP Chemistry. *They are intended to assist AP workshop consultants as they develop training sessions to help teachers better prepare their students for the AP Exams*. They give an overview of each question and its performance, 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 included. Consultants are encouraged to use their expertise to create strategies for teachers to improve student performance in specific areas.

Question 1

What was intended by the question?

The question was designed to measure students' understanding and abilities relating to the topics of pH, weak-acid equilibria, titration of a weak acid with a strong base (including pH at equivalence), preparation of a buffer solution, and oxyacid strength. The question involved both quantitative calculations and some short answers.

How well did students perform?

Students performed fairly well, but they were better on the calculation parts than on the short answer parts. Students typically earned points for part (a), part (b), part (c)(i), and part (d).

What were common errors or omissions?

In part (a):

- Responding with the answer for $[H^+]$, but showing no work
- Confusing natural log (ln) with log base 10 ($\log_{10}$)
- Obtaining an excessively high ($10^{4.95}$) or negative $[H^+]$
- Excessive number of digits in answer

In part (b):

- Writing only the ratio of the dissolved species and eliminating any equality to K_a
- Confusing K_a with K_{sp}, K_c, or the rate constant, k
- Writing expressions lacking [HOBr], or equating [HOBr] to $[OBr^-]$

In part (c)(i):

- Ignoring the stoichiometric ratio, or assuming it to be 1:1
- Improperly applying the correct stoichiometric ratio
- Using a direct proportion to calculate volume (from $M_aV_a = M_bV_b$)

In part (c)(ii):

- Attributing pH >7 to the condition that a weak acid is titrated with a strong base
- Ignoring the presence of OBr^- at the equivalence point, citing the cause as the presence of the "strong" base (*vs.* weak acid)
- Citing the cause as the excess ion from $Ba(OH)_2$
- Simply stating the ion is the conjugate base of a weak acid
- Incompletely explaining hydrolysis
- Implying that $pH = pK_a$ at the equivalence point

In part (d):

- Substitution of moles into the equilibrium expression
  (There is no volume change in the problem, so correct answers are obtained. However, there is no evidence that students understand why this happens).

In part (e):

- Assuming the H is bonded directly to Br, especially in $HBrO_3$
- Simply citing the fact that there are more oxygen atoms in $HBrO_3$
- Confusing O atoms in $HBrO_3$ with O atoms in a separate molecule (e.g., O_3)
- Not differentiating between hydrogen bonding (intermolecular) and H–O covalent bonding (intramolecular)

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

Continue to emphasize that an answer should be supported with work, use of units, and use of significant figures (especially significant figures in logs).

Regarding acid-base chemistry, involve students in explaining the chemistry at the particle level for equilibrium and titration problems. Encourage students to explain phenomena more deeply. Discourage responses that simply state rules such as "strong acid-weak base titrations are basic at the equivalence point" or "more oxygen atoms in a formula make the acid stronger."

Encourage your students to use stoichiometry from the balanced neutralization reaction to calculate the volume of acid or base required to neutralize (react with) the base or acid, and not to use the equations $M_1V_1 = M_2V_2$ or $M_aV_a = M_bV_b$. The equation $M_1V_1 = M_2V_2$ should be used for dilutions only.

Emphasize the recognition of which species define the pH at important points during an acid-base titration. (There are four critical points; before any base is added, between the initial pH and the equivalence point, at the equivalence point, and beyond the equivalence point.)

Use the "ICE" table set-up for equilibrium systems. An ICE table specifies the ***i***nitial, ***c***hange, and ***e***quilibrium conditions and, when completed correctly, provides students with all the information required to successfully solve an equilibrium problem.

Question 2

What was intended by the question?

This question tested students' knowledge of chemistry in three areas — stoichiometry (limiting reactant), electrochemistry (cell potential under standard and nonstandard conditions), and thermodynamics (Gibbs free energy under standard and nonstandard conditions).

How well did students perform?

This question was chosen by 43 percent of the students. As a group, these students performed reasonably well on the question; the mean score was 4.56 points out of 10 points. In general, students tended to earn the most points in parts (a), (b), and (c).

What were common errors or omissions?

In part (a)(i):

- Not relating 2 moles of Ag^{+} to 1 mole of Zn
- Getting the proper number of moles of reactants with the correct ratio, but then failing to determine the limiting reactant
- Not explaining how the numbers generated determine the limiting reactant

In part (a)(ii):

- Calculating the moles of Zn^{2+}, but then not using the volume to determine the concentration, or incorrectly calculating the number of moles of Zn^{2+}, even though calculation of concentration was done appropriately
- Stopping at the step in which the number of moles of Zn^{2+} produced is determined
- Being inconsistent with part (a)(i). If Zn is the limiting reactant, then the concentration of $[Zn^{2+}]$ must reflect this
- Using incorrect number of significant digits in answer

In part (b):

- Doubling the voltage of the Ag^{+} half-reaction
- Not changing the sign of the Zn half-reaction
- Subtracting the two half-cell voltages

In part (c):

- Not indicating the sign of the free energy
- Not including appropriate units (J, kJ)
- Using +1.56 volts for the E^{o} value or another calculated value; not recognizing that +0.46 volts is the value of E^{o} to use in the calculation
- Using a value of n other than 2 (e.g., 1, 3, and 6)
- Reporting answer with incorrect number of significant digits

In part (d):

- Calculating the natural log of Q rather than the base 10 log of Q
- Using the wrong value of n, as in part (c)
  (If a student was consistent in part (c) and part (d) with the wrong value for n, no points were lost in part (d).)

- Reporting answer with incorrect number of significant digits
- Incorrectly substituting into the Q expression

  (Common incorrect substitutions were $\frac{[Cu^{2+}]}{[Ag^{+}]}$, $\frac{[Cu^{2+}]}{[Ag^{+}]^2}$, and $\frac{[Ag^{+}]^2}{[Cu^{2+}]}$.)

In part (e):

- Referring to the E for the cell instead of E for the cell under the specified conditions

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

Stoichiometry should be a subject that is reexamined throughout the school year. The balanced chemical reaction is still one of chemistry's best tools.

When teaching students how to determine limiting reactants, perhaps try more than one method. As demonstrated by the student responses, there are many ways to answer (a)(i), and perhaps some of your students will grasp these alternative methods.

Remind students that molarity is moles divided by liters. Many students confused <u>moles</u> of Zn^{2+} with the <u>molarity</u> of Zn^{2+}.

Have students practice using the standard reduction table to calculate cell voltage in cases where the coefficients in the balanced equation are <u>not</u> in a 1:1 ratio.

Have students practice using the Nernst equation. Emphasize both the use of the correct number of electrons in the cell-reaction equation and the proper use of Q.

Help your students relate electrochemistry to thermodynamics. Have them create a table relating E, ΔG, and the spontaneity of the reaction.

Finally, stress that when a question asks for an answer and a justification that BOTH should be given. Too many students lost points because they gave the correct answer, but their justification was too weak. Recommend that any "support your answer" response is best done with a sentence.

Question 3

What was intended by the question?

Using the context of a simple hydrocarbon, this question was designed to evaluate students' knowledge and ability to apply stoichiometry and use the ideal gas law and Graham's Law. In addition, abilities to perform thermochemical calculations and to draw structural isomers of a simple hydrocarbon are assessed.

How well did students perform?

This question was chosen by 57 percent of the students. In general, students were able to balance the equation correctly and recognize the application of the ideal gas law. Some students were adept at substituting in the formula and using the correct mole ratio from the equation. Others broke their calculations down into several steps by calculating moles, used the combined gas law to account for pressure and temperature changes, and then related the results to the equation given. This approach indicated that these students had a sound understanding of the concepts. In calculating the molar mass of the unknown gas, many students used Graham's Law correctly. Others used the root-mean-square formula. Students generally earned points in parts (a), (b), and (c).

What were common errors or omissions?

In part (a):

- Incorrectly balancing the equation for the combustion reaction.

In part (b):

- Not adjusting the volume for the given temperature and pressure conditions
- Using the number of moles of C_5H_{12} rather than moles of CO_2 when substituting in the ideal gas formula
- Using the incorrect value for *R*

In part (c):

- Neglecting to indicate the negative sign for ΔH

In part (d):

- Incorrectly substituting in the Graham's Law equation
- Dividing the molar mass of C_5H_{12} by 2
- Using the incorrect number of significant figures (e.g., reporting the molar mass of the unknown gas as 18 g mol^{-1})

In part (e):

- Not understanding what isomers are and/or how to draw them using structural formulas (Many students redrew the structure given in the question in different arrangements that suggested they did not understand free rotation about a single bond.)

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

Emphasize to students that they must read each question carefully and then answer what is being asked. For example, in part (c), the value of ΔH was asked for, but many students failed to indicate the negative sign. Also, even though the molar mass of C_5H_{12} was given in the problem, many students did not use this information, but rather they often calculated the molar mass incorrectly or used other numbers.

Advise your students NOT to restate the question in their responses. This is an unnecessary and a wasteful use of limited time and is not in a student's best interest.

Stress to your students that they must show their work in quantitative questions, or risk losing credit. Most of the credit available is focused on process, not on final answers.

Work with your students in drawing structural isomers. Discuss with them the idea of free rotation about C–C single bonds and the difference between a structural isomer and a conformer.

Question 4

What was intended by the 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 (including principles of periodicity) in predicting the products(s) of a variety of chemical reactions.

How well did students perform?

In this question, students choose to answer five of eight reactions. The most popular choices were the lead iodide precipitation reaction (a), the combustion of phosphorus reaction (b), the cesium oxide plus water reaction (c), and the acid/base reactions (f) and (h). Students seemed the most proficient at predicting these products: PbI_2, $Cs^+ + OH^-$, and $Zn^{2+} + H_2S$. Most recognized that a decomposing hydrogen carbonate produced CO_2 and that an acid/base reaction produced water. Many students failed to write the reactant NH_4Cl in equation (h) as a solid. Frequently the only 3 points a student earned for this question were for reaction (a). The mean score was 5.54 points out of 15 points, which is lower than it has been for this question in the past few years.

What were common errors or omissions?

Reaction (a): Many students did not know that NaI and $Pb(C_2H_3O_2)_2$ are soluble compounds, that Pb is a +2 ion, and that I is a –1 ion. Often net ionic equations were done incorrectly.

Reaction (b): Though many students were able to correctly identify that P and O_2 were the reactants, fewer seemed to know the products. Charges were often assigned to the P and O_2 species. Interestingly, a common answer for the products was CO_2 and H_2O, which many students know as the products of burning carbon compounds.

Reaction (c): Many students were unable to correctly identify the symbol for cesium — they often used Ce. Often the charges of the species were incorrect, and cesium hydroxide was often treated as insoluble.

Reaction (d): This reaction was the least frequently chosen of the eight reaction options. Many students did not know that $CoCl_2$ was soluble and that excess HCl drove the reaction to form the complex ion. Some students did not recognize that HCl was a strong acid and dissociates in water to form ions.

Reaction (e): Typically, students who chose this reaction did not know the decomposition products. Both Na and NaOH were sometimes given as products.

Reaction (f): Many students did not know the insolubility of ZnS or the fact that HCl is dissociated in water.

Reaction (g): Students often treated this as a precipitation reaction. Many did not recognize that acidified means having H^+ ion as a reactant. Other frequent errors were indicating the charge of permanganate ion to be –2, and not knowing the reduction product of permanganate in an acidic solution (Mn^{2+}).

Reaction (h): Students who chose this reaction often answered it correctly. A frequent error was not showing the ammonium chloride as a solid on the reactant side of the equation. As with many of the reactions, students often performed poorly because they did not know or apply solubility rules and/or follow the rules for writing net ionic equations.

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

Emphasize the following with your students:

- know the solubility rules
- recognize and write net ionic equations
- understand that strong acids are completely dissociated in water and that strongly heating a substance does not mandate that oxygen is a reactant
- distinguish between oxidation-reduction and precipitation reactions
- write formulas of elements and compounds
- know the charges of common cations and anions

Provide learning opportunities for students to learn descriptive chemistry, and how to predict products and write equations for reactions (include reactions that cannot be performed in the school laboratory.) Also include both complexation reactions and oxidation-reduction reactions in acidic or basic solutions.

Require students to know the symbols for the first twenty elements in the periodic table, plus the more commonly studied elements with atomic numbers greater than 20. Remind students that if they write the oxidation numbers of elements in a compound as a note to themselves as they determine the products of the reaction, they should be careful to delete these numbers in the final answers. It is important for students to write superscript charges for only those species that exist as ions in the final net-ionic equation that will be scored.

Question 5

What was intended by the question?

Required laboratory questions are designed to assess whether students understand the procedures and purposes of commonly performed chemistry laboratory experiments. This year, the question asked a series of specific questions concerning a “coffee-cup calorimeter” determination of the heat of neutralization of an acid-base reaction. In order to keep the arithmetic simple, 1 molar solution of HCl and NaOH were mixed in equal volumes, a neutralization reaction with 1:1 stoichiometry was selected, and the equation $q = mc\Delta T$ was provided. Students were also advised that solution densities were the same as water, their specific heat capacities were the same as water, and that heat losses from the mixed solution were negligible.

How well did students perform?

In general, students did poorly on this question (the mean score was only 3.18 points out of 10 points), although some students had excellent answers. In terms of points earned, parts (a), (b), and (e) were the most successfully answered, while parts (c) and (d) proved to be more difficult for the students. Many students were not careful in answering parts of the question, failing to include sufficient detail.

What were common errors or omissions?

In part (a):

Students were asked to identify the units of the terms in the equation $q = mc\Delta T$. Typically, students did recognize the correct meaning and units of the terms in the equation. Errors demonstrated in this part included:

- Using units for terms in the equation as if they were standard across the fields of chemistry and physics (e.g., c = speed of light, ΔT = time difference, q = charge in coulombs)
- Neglecting units for terms on the left hand side of the equation
- Identifying what the term symbol represented (e.g., m is mass) but not indicating the units

In part (b):

Students were asked to list the measurements that must be made to obtain q. Many students successfully identified the volume or mass of solution (reactants or final mixture) as one measurement and the initial and final temperatures of the mixed solutions as the other vital measurements. Misconceptions or errors demonstrated in this part included:

- Indicating that the mass of water produced in the reaction is needed for the calculation of q
- Indicating that the mass of H^+ is the same as the mass of the HCl solution
- Saying to measure "mass" with no statement as to which mass to measure
- Confusing measurements with a calculation, as in T_i and T_f *vs*. ΔT

In part (c), students were asked to explain how to calculate (i) the number of moles of water formed during the experiment and (ii) the value of the molar enthalpy of neutralization for the reaction. Relatively few recognized that because of the simple stoichiometry and the unit solution molarities, the moles of water produced is directly equal to the number of liters of either reactant used. Students who can reason through such short cuts should earn the credit, with the caveat that they must explain them clearly. Misconceptions or errors demonstrated in part (c)(i) included:

- Giving equations and not explaining how to substitute into them
- Taking valuable time to explain how to determine the limiting reagent (an unnecessary step in this case)

Misconceptions or errors demonstrated in part (c)(ii) included:

- Using the mass of water produced instead of the total mass of solution in the cup for m in the equation for q
- Inappropriately using the equation $\Delta H = \Sigma\ \Delta H_f$ products – $\Sigma\ \Delta H_f$ reactants (perhaps because this equation is listed on the formula sheet)
- Inappropriately using the equation $\Delta H = C_p\Delta T$ (again, listed on the formula sheet)

In part (d), students were asked to justify a prediction of the results for (i) q and for (ii) ΔH_{neut} if the molarities of the reactants were changed to 2 M, while keeping everything else the same.

Misconceptions or errors demonstrated in part (d)(i) included:

- Focusing on the m term instead of the ΔT term in the q equation and stating that if the mass doubles then q must double

Misconceptions or errors demonstrated in part (d)(ii) included:

- Indicating that ΔH_{neut} values are proportional to mass or molarity of reactants
- Stating that a proportion is involved but not clearly identifying what exactly the proportion is

In part (e), students were asked to predict the effect on the value ΔH_{neut} if heat were lost to the surroundings. Most students were able to make the prediction that a lower value would be obtained, however they frequently failed to justify this prediction fully. Misconceptions or errors demonstrated in part (e) included:

- Stating that heat loss does not affect ΔT or q but directly changes ΔH
- Assuming the heat loss was small and thus simply an "error"
- Confusing theoretical determinations of ΔH with the measurement in this experiment

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

Because this may be an experiment done in the first chemistry course for some students, have them review all the laboratories done throughout their chemistry career shortly before the exam.

Make sure that students understand the reasons for all steps in laboratory experiments and calculations and all the terms in any equations used. Construct quizzes, hold classroom discussions or use other strategies to assure that students understand what they are doing and why.

Have students outline procedures for manipulations and calculations for a laboratory experiment some time after doing the experiment WITHOUT the aid of the laboratory write-up to assist with memory.

If you ask students to collect all their laboratory reports neatly in a folder for possible review by colleges, consider doing this before the AP exam so students can review what they have done.

Ask students to describe the measurements that are taken in a laboratory experiment. It is good practice to assume the person reading a laboratory report has not done the experiment, so it is a good idea to explain in detail.

Question 6

What was intended by the question?

This was the required essay question, which has four parts in which students explain chemical observations in terms of principles of atomic structure and chemical bonding. This type of question is designed to assess students' ability to apply their chemical knowledge by formulating coherent responses that fully explain the observations.

How well did students perform?

The students did not perform well on this question (average score 2.93 points out of 8 points), earning an average of less than 1 point per part. In terms of points received, the parts in order of increasing difficulty were (c), (a), (d), and (b).

What were common errors or omissions?

In part (a):

Many students correctly identified that the smaller radius of Be is due to the greater number of protons in Be. However, many failed to earn the second point, which required them to argue in more depth — that it is also important that the valence electrons be in a similar subshell (shell was accepted) for this argument to be valid. A small group of students identified increased effective nuclear charge as the key causative factor, but many of these students showed that they did not really understand this concept.

Students frequently showed misconceptions by stating or implying the following:

- Electron shielding or pairing energy is more important in determining atomic radius than nuclear charge is
- The electron/proton ratio for atoms changes across the period
- Two electrons have twice the attraction to a nucleus as one electron
- Electronegativity is an explanation, not a result
- Electrons are point charges pulling the nucleus towards them
- Atomic radius is determined by the size of the nucleus

In part (b):

Most students identified that for K, the second electron must be taken from a more stable (octet) core, whereas only a valence electron is removed from Ca. However, they typically neglected to explain <u>why</u> it requires more energy to remove an octet electron.

Students frequently showed misconceptions by stating or implying the following:

- Electrons in Ca “want” to become an octet so the second ionization energy is “very low,” perhaps even lower than the first ionization energy
- K becomes the element Ar when it ionizes; when Ca loses one electron, it becomes the element K
- Filled shells have extra screening from the nucleus so they are more stable than half-filled shells
- The octet rule completely explains this difference
- Ar is a “happy” element that others want to become or remain as
- Ionization energy is defined as energy needed to add electrons
- It is easier to ionize unpaired electrons than paired electrons

In part (c):

Students were not expected to know the names of these compounds, and most identified by words or diagrams that the ethene molecule has a C–C double bond and the ethane molecule has a C–C single bond. However, many did not go on to explain <u>why</u> the C–C bond in ethene has greater energy than the C–C bond in ethane. Many students repeated or paraphrased the phrase in the question “the bond in C_2H_4 has a greater bond energy than in C_2H_6” and earned no points for this “explanation.”

Students frequently showed misconceptions by stating or implying the following:

- When bonds form, energy is absorbed (rather than released)
- Pi bonds are stronger than sigma bonds
- A double bond is twice as strong as a single bond
- Hydrogen bonding occurs in hydrocarbons
- Since there are more bonds in C_2H_6 compared to C_2H_4 , the bonds in C_2H_4 are stronger

In part (d):

Most students identified that the higher boiling point is the result of greater intermolecular forces and that these forces are London dispersion (or Van der Waals) forces. Students had more difficulty explaining why bromine has greater forces, though a significant number did identify the size of the electron cloud as leading to greater possibilities for induced-dipole forces.

Students frequently showed misconceptions by stating or implying the following:

- Bromine is denser (or heavier) so it takes longer to heat up
- Bromine has more particles so it heats up more slowly
- Boiling relates to how fast molecules are moving and how fast things can heat up
- Boiling involves breaking covalent bonds in molecules
- London dispersion forces are only dependent on mass, or on electronegativity
- Boiling point of an element is a colligative property and depends on molarity

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

Students exhibited the following difficulties in answering this question:

- Presenting trends as explanations (no credit was earned for this)
- Presenting circular arguments or tautologies (e.g., Li is larger than Be because Be is smaller than Li)
- Presenting partial explanations (earning 1 but not 2 points)
- Anthropomorphizing atoms (using “lecture language”), describing “happy” atoms, or atoms that “want” to lose electrons
- Being sloppy with language and interchanging terms (e.g., neutron for proton, neon for argon, bond for force, period for group, atom for molecule, and molecule for atom)

To better educate students and prepare them to earn possible credit and or placement by getting a higher grade on the AP Chemistry Examination, teachers should do the following:

- Review the problem issues and misconceptions identified above
- Emphasize that in questions involving energy and charge there are always <u>two</u> parameters to consider: (1) the magnitudes of the charges, and (2) the distance separating them
- Practice with students to challenge “necessary, but not sufficient” explanations
- Emphasize that anthropomorphic language/terminology is not acceptable on the examination (even though it may help understanding initially)
- Emphasize the importance of using correct terminology
- Emphasize that trends and rules (e.g., the octet rule) are NOT explanations

- Emphasize that well organized, clear answers are more likely to get partial credit than disorganized ones. Train your students to read their own answers for meaning, that is to look for bad logic (tautologies), lack of clarity, and needless repetition
- Emphasize that it is an unnecessary waste of time to rewrite the question in an answer
- Instruct students to construct their answers so they make reference to all parts of the question in a way that the scorer (AP Reader) can understand what is being answered

Question 7

What was intended by the question?

This question was designed to assess students' ability to apply their knowledge of chemical kinetics in a real-world context.

How well did students perform?

This question, one of the two options for the "other" essay question, was chosen by 58 percent of the students. Many students performed well on this question, which had an average score of 4.20 points out of 8 points. Students seemed to have the most difficulty with part (d)(iii).

What were common errors or omissions?

In part (a):

- Some students included the intermediate on both sides of the equation and did not earn the point. (Students were not penalized if they included the catalyst, Cl, on both sides of the equation.)

In part (b):

- Most students correctly identified Cl as the catalyst. Their justification was often given as a textbook definition of a catalyst rather than describing the connection of the catalyst to the steps in the mechanism.
- A common misconception appeared to be the belief that if a catalyst does not appear in the final balanced equation, then it has no effect on the reaction

In part (c):

- Most students correctly identified ClO as the intermediate
- Typically, students did not earn the justification point because they did not connect the intermediate to a product formed in one step and a subsequent reaction in a following step
- Students often had trouble clearly discriminating between the catalyst in part (b) and the intermediate in part (c)
- More students were able to explain why ClO was an intermediate than were able to explain why Cl was the catalyst

In part (d)(i):

- Most students correctly identified the overall reaction order
- A common error was to conclude that the reaction was first order because both exponents in the rate law were equal to 1

In part (d)(ii):

- Many good students (as judged by their performance on the other parts of the question) appeared to have difficulty with the algebra involved with the units
- No point was earned for correct units for zero or first-order reactions because the specific rate law was given in the question
- Student answers often showed little difference among the symbols written for *M* (molarity), m, and mol
- Students sometimes confused the rate constant with K_{eq}

In part (d)(iii):

- Most students correctly identified the rate determining step as Step I by explaining that Step I contained the reactants that were also contained in the given rate law expression
- A common error was failure to connect the slow step to the given rate law

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

Teachers should emphasize that textbook definitions alone do not constitute good explanations or justifications. Students should practice writing out brief explanations so that careless or incorrect use of terminology can be avoided.

Teachers should give their students practice in writing units associated with first and second order reactions. Students should be able to see the connection between the reaction order and the units. Careful distinction should be made between a particular reactant's order and the overall reaction order.

Simple reaction mechanisms should be taught. Students should have practice writing simple mechanisms from a given rate law. They should also have practice predicting a given rate law from a simple mechanism.

Question 8

What was intended by the question?

This question was rather straightforward and was designed to assess students' understanding of thermodynamics, including changes in entropy, changes in enthalpy, and the effect of solids in reactions that are at equilibrium.

How well did students perform?

This question was less popular than question 7, and was chosen by 42 percent of the examinees. The average score was 3.71 points out of 8 points. Points were most often earned in parts (a), (b), and (c).

What were common errors or omissions?

In part (a):

- Some students thought that the change in entropy was negative, since two substances produced only one product
- Students often assigned the wrong sign to the value of ΔS even though they provided a correct explanation

In part (b):

- Often students did not fully explain both the reaction shift and placement of the heat term in the equation

In part (c):

- Many students did not seem to be familiar with an energy diagram for a reaction. When they did draw it correctly, frequent errors were to leave out E_a (no penalty) and to label the change in enthalpy incorrectly.

In part (d):

- Many students did not know that solids, when present in a reaction, have a constant concentration and are not included in expressions for equilibria
- Many students correctly answered that [CO] did not change, but then attributed this to a limiting reactant situation

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

Teachers can improve their students' performance by emphasizing:

1) the implication of signs in changes of entropy, enthalpy, and Gibbs' free energy,
2) the need for practice in drawing energy diagrams, and
3) that all explanations should be organized and complete.