The College Board AP® ADVANCED PLACEMENT PROGRAM®

Student Performance Q&A:

2003 AP® Chemistry Free-Response Questions

The following comments on the 2003 free-response questions for AP® Chemistry were written by the Chief Reader, John Gelder of Oklahoma State University in Stillwater, Oklahoma. 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?

The question was designed to measure students' understanding and abilities relating to the topics of weak-base equilibria, pH, titration of a weak base with a strong acid, pH at equivalence, and appropriate titration indicator selection. The question involved both quantitative calculations and a short answer.

How well did students perform on this question?

Students performed fairly well on some parts but poorly on others. They typically earned points for Part (a) (one point), Part (b) (three points), and Part (e) (one point). The mean score was 3.35 out of a possible 10 points.

What were common student errors or omissions?

Part (a)

- Most students wrote the equilibrium expression correctly.
- Infrequently, $[H_2O]$ was included in the equilibrium expression.

Part (b)
In this part students:

- used $[H^+]$ instead of $[OH^-]$ in the K_b expression (failing to convert pH to pOH);
- set $[C_6H_5NH_2] = [C_6H_5NH_3^+]$ (usually as 0.1 M), instead of $[C_6H_5NH_3^+] = [OH^-]$; and
- used moles (computed by 0.025×0.1), instead of molarity for $[C_6H_5NH_2]$.

Part (c)
In this part students:

- used the equilibrium concentration of hydroxide from Part (b) and assumed a strong acid-strong base titration of this with HCl (resulting in leftover acid),

- failed to distinguish between $[OH^-]$ and $[H^+]$ or between pH and pOH, and
- subtracted molarities instead of moles to get equilibrium amounts after titration.

Part (d)

In this part students:

- did not recognize that the solution volume has doubled at equivalence so $[C_6H_5NH_3^+]$ is halved;
- assumed that at equivalence the concentrations of $[C_6H_5NH_3^+]$ and $[C_6H_5NH_2]$ are equal and thus cancel in the equilibrium expression or that the Henderson-Hasselbalch log ratio equals 1, so that $pH = pK_a$ at equivalence;
- assumed that at equivalence the pH is equal to the value calculated in Part (c); and
- assumed that at equivalence $[OH^-]$ must equal $[H^+]$, so $pH = 7$.

Part (e)

- Students usually missed this part only if they gave very weak explanations or gave a choice and explanation that did not agree with the pH calculated in Part (d).
- Another error was stating that the pK_a of the indicator must be equal to the pK_a at the equivalence point.
- A few students concluded that an acid (erythrosine) was always needed to titrate a base.

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?

- Continue to emphasize that an answer should be supported with work and use of units.

- 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 and to refer to the specific chemistry in any problem. Discourage responses that simply state rules such as "strong acid-weak base titrations are acidic at the equivalence point." However, encourage students to check their results against these rules and review their work if the resulting value seems in conflict with the rules.

- Encourage students to write a balanced equation for neutralization or hydrolysis reactions before using stoichiometry to calculate the amounts reacting during titrations 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 non-reacting dilutions only. Have students distinguish carefully when molarities and moles are appropriate to use in solution reaction calculations.

- Emphasize the recognition of which species define the pH at important points during an acid-base titration. (There are four critical points: before any titrant is added, between the initial pH and the equivalence point, at the equivalence point, and beyond the equivalence point.) If you allow use of the Henderson-Hasselbalch equation, emphasize when it is not useful (before the addition of titrant and at the equivalence point).

- Use the "ICE" table setup for equilibrium systems. An ICE table specifies the initial, change, and equilibrium conditions and, when completed correctly, provides students with all the information required to successfully solve any equilibrium problem.

- Encourage students to add comments in a response when a numerical result appears to be incorrect. This may give readers a reason to look again for partial credit points. For example, “This pH value (14.6) must be wrong, since pH is unlikely to be highly basic for this reaction!”

- It was evident that students have difficulty using the Henderson-Hasselbalch equation correctly. Some confusion arose because Part (c) asked for the pH along the titration curve of a weak base and a strong acid. Students might use the Henderson-Hasselbalch equation correctly but have the wrong concentrations substituted. Teachers are encouraged to have their students develop a deeper understanding of how to solve for the pH on a titration curve.

Question 2

What was the intent of this question?

This question tested students’ knowledge of physical and chemical changes in gaseous systems. Calculations or explanations involved applications of stoichiometry (limiting reactants) and gas laws (Ideal Gas Law, partial pressure, and Graham’s Law of Effusion).

How well did students perform on this question?

Students could choose between Question 2 and Question 3. This question was chosen by 50.8 percent of the students. The mean score for Questions 2 and 3 was 4.51 out of a possible eight points. Students who chose Question 2 tended to earn points in Parts (a), (b), and (d) more often than in Parts (c) and (e).

What were common student errors or omissions?

Part (a)
In this part students:

- used atomic mass (14.01 or 16.00) to calculate moles of N_2 and O_2, respectively;
- added molar masses to calculate moles; and
- used the incorrect value of R in calculations.

Part (b) (i)
In this part students:

- used grams to calculate the mass fraction instead of the mole fraction, and
- wrote “1/2” for the mole fraction without setup as support.

Part (b) (ii)
In this part students:

- calculated moles of N_2 from $n = \dfrac{P_{298}V}{RT_{280}}$ and used the answer to determine mole fraction;
- calculated P_{N_2} and then applied $P_i = x_iP$, where $P = P_{N_2}$ (from the previous answer), so that the mole fraction was applied twice; and
- used the wrong temperature in the setup (298 K instead of 280 K).

Part (c)
In this part students:

- assumed the mole ratio would not change because the mixture was equimolar in N_2 and O_2, the difference in molar mass was insignificant, or the temperature and/or pressure of each gas was the same;
- attributed the decrease in ratio to the smaller size or radius of N_2 (due to triple bonds) and ignored molar mass or molecular speed as a factor;
- predicted an increase or decrease based on air leaking into the sealed container; and
- used a kinetic energy explanation instead of a speed explanation.

Part (d)
In this part students:

- wrote equations in other than lowest whole-number terms or net-balanced formats (points were awarded, but the style was not consistent with expected form for balanced equations), and
- reported excess O_2 or O as a product.

Part (e)

- Inadequate recognition of the limiting reactant component of the problem led to such errors as determining the product based on multiples of 0.176 moles of NO, ignoring the fact that a reaction was taking place, and using initial moles and eliminating the excess reactant in calculating the pressure.
- Readers also found inadequate setup of work, such as substituting moles into the calculations for gas pressure with no prior stoichiometry calculations.

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?

- Stoichiometry should be a subject that is reexamined throughout the school year. The balanced chemical equation is still one of chemistry's best tools. Provide suggestions for recognizing limiting reactant problems.
- Remind students to use formula masses, not atomic masses, in mole calculations with diatomic elements.
- Reinforce the use of units and significant figures (especially for values ending in zeros) in problem solving.
- Stress using specific terminology. Avoid terms like "small" without reference to a particular dimension.
- Help students associate a pressure value with a specific temperature.
- Stress kinetic molecular theory explanations of a variety of gas laws.
- Review test-taking strategies for the AP Chemistry Exam: showing all work, monitoring time allocations, and bringing a calculator. Stress the importance of showing all work, however simple and automatic, when determining an answer on the exam. Many students lost the initial point in this problem because only the value (0.875 or 1.75 total) was shown for moles of the gases. Students showed they ran out of calculator time by doing the long divisions at the side of the problem.

Question 3

What was the intent of this question?

This was a kinetics experiment question that tested students' familiarity with reaction rates and electrochemistry topics. Students needed to be able to determine a rate law by comparing four experiments with different initial concentrations of reactants. By comparing the experimental data, students were to determine the reaction order for each reactant and then write a complete rate law. The question involved a redox reaction and required calculation of the cell potential and the number of electrons transferred.

How well did students perform on this question?

Students could choose between Question 2 and Question 3. This question was chosen by 49.2 percent of the students, and they performed reasonably well on it. The mean score for Questions 2 and 3 was 4.51 out of a possible eight points.

What were common student errors or omissions?

Part (a) (all subparts)

- Students who had difficulty determining the rate law did not understand that initial concentrations are fixed in the experiments and the rate of disappearance is the measured data.
- Students earned no points for answers that described concentration and rate changes without clear reference to data.
- Some students did not appear to know what a reaction order is. This was indicated by solving for orders in Part (c) after clearly giving an unsupported or different answer in Part (a). These answers did not earn points for Part (a).

Part (a) (i)

- This seemed the easiest point to get, wherein "double concentration: double rate" was the most common answer. Some students described doubling [Br^-] without being specific about what happened to the rate.

Part (a) (ii)

- Students had trouble with the fact that the change in concentration and rate change between Experiment 1 and Experiment 3 was not a whole number (1.5).

Part (a) (iii)

- Many students ignored other changing concentrations and said $2^x = 8$ and the order is 3. Other common orders were 0 and 1.
- Some students indicated that the order could not be calculated because only one of the three species had a constant concentration.
- Some students invented new lines to help them solve this part.

Part (b)

- Some students derived the rate law from an equilibrium expression.
- Many wrote a rate law without a *k*. This gave them nothing to solve for in Part (c).
- Some wrote an equilibrium expression; others used the coefficients of the balanced equation as the orders.
- Some responses were inconsistent with the orders determined in Part (a).

Part (c)

- Often the units were incorrect or ignored.
- Incorrect use of abbreviations, such as "m" for mole, and incorrect signs on powers cost students points on this part.

Part (d)

- Common errors were the wrong sign convention, multiplying voltage by stoichiometric coefficients, or using the Nernst equation to solve for voltage.
- Not showing work was common and resulted in no points for this part.

Part (e)

- A response of 10 e^- was accepted if a rationale based on balancing the electrons in the half reactions was given. Multiplying five moles of electrons by 6.02×10^{23} to get the actual number of electrons was also accepted.
- Incorrect calculations included "5 + 5 = 10" (students did not understand these were the same electrons), "5 + 2 = 7", or "0" (because electrons cancel in the balanced equation).

General Comment

- Some students did not understand the difference between equilibrium *K* and kinetics *k*.

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

- Do rate problems with three or more reactants and give examples where the concentration of more than one reactant is changed from one experiment to another.

- Encourage students to use math to deduce rate laws. Descriptions of concentration and rate changes are often unclear to readers. Math versions are easier to follow, clearly establish which experiments are used, and maximize opportunities for students to earn points.

- Be specific about *K* (the equilibrium constant) versus *k* (the rate constant).

- Practice showing complete setup of calculations to support an answer.

- Train students in dimensional analysis, with emphasis on proper labels.

- Always show work. It is sad to have students with correct answers get a zero on a part of a question because they did not show any work.

- Be sure students understand electron movement in a voltaic cell and that voltage does not change with coefficients.

Question 4

What was the intent of this question?

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

How well did students perform on this question?

In this question students choose five of the eight reactions given. The most popular choices were (c) the decomposition of hydrogen peroxide, (d) the acid-base reaction, and (g) the single replacement of strontium. Most recognized that a decomposition of hydrogen peroxide produced H_2O and O_2 , and that an acid-base reaction produced water. Many students failed to write the reactant "AgCl" in Equation (e) as a solid. Students performed very well on this set of equations. The mean score was 8.04 out of a possible 15 points, which is higher than it has been in the past few years.

What were common student errors or omissions?

Reaction (a): Many students incorrectly represented the reactants as compounds instead of ions. They often failed to recognize that calcium phosphate is an insoluble precipitate. The charge and formula given for the phosphate ion was often incorrect. Less frequently, the wrong symbol and/or charge were given for the calcium ion.

Reaction (b): Many students failed to represent zinc carbonate as a solid compound. Other common mistakes included the formation of carbonic acid (H_2CO_3) instead of carbon dioxide and water, and forgetting that sulfuric acid is a strong acid.

Reaction (c): Many students were able to earn full credit for this reaction. A common mistake was the production of hydrogen gas and oxygen gas as the two decomposition products.

Reaction (d): Many students performed well on the acid-base question. The most common mistakes included leaving all four ions on the reactant side of the equation and indicating that calcium chloride is insoluble. Solubility rules are a must!

Reaction (e): Many students failed to include AgCl as a solid reactant and therefore were unable to earn full credit. A number of other students failed to give the correct formula for the diammine silver complex. Another common mistake was writing ammonia as NH_4 .

Reaction (f): Many students performed well on this equation and earned full credit. The most common mistake was the misconception that all things that burn produce carbon dioxide and water. Other mistakes included writing the formula for magnesium oxide as MgO_2 and expressing magnesium as Mg^{2+}.

Reaction (g): Most students who attempted this equation earned full credit. The most common mistake was not ionizing copper(II) nitrate and strontium nitrate.

Reaction (h): Most students earned the reactant point for this equation but failed to correctly predict the products. Common mistakes included not ionizing nitric acid and producing NO_2 and/or OH^-.

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

Emphasize the following with your students:

- knowing the solubility rules,
- recognizing and writing net ionic equations,
- understanding that strong acids are completely dissociated in water,
- distinguishing between acid-base and precipitation reactions,
- writing formulas of elements and compounds correctly,
- knowing the charges of common cations and anions (including oxyanions),
- writing the final net ionic equation in the given space,
- removing spectator ions before writing the final answer in the given space (only items appearing in the answer box are graded), and
- writing superscript charges for only those species that exist as ions in the final net-ionic equation.

Remind your students that:

- balancing of equations is not graded and is time consuming for them,
- balancing of formulas (subscripts) is required, and
- representing phases of matter is not scored.

Question 5

What was the intent of this 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 the spectrophotometric determination of the concentration of a $CoCl_2$ solution. Students were presented with a list of available volumetric glassware and graphical data and asked to describe the laboratory manipulation of the glassware and the interpretation of the data.

How well did students perform on this question?

In general, students performed better than they had on prior laboratory questions. It was apparent that many students had performed similar laboratory procedures. The mean score was 3.5 out of a possible nine points. The parts of the question most frequently answered correctly were the interpretation of the graphical data and the description of the effect of fingerprints on the cuvette. The least frequently earned point was for the second factor in Beer's law.

What were common student errors or omissions?

Part (a)

In this part students showed:

- an inability to calculate the correct volume of stock solution required,
- a failure to describe appropriate use of the volumetric flask (i.e., diluting to the mark), and
- a failure to restrict the description to the provided glassware (many students prepared solutions with total volumes other than 100 mL).

Parts (b) and (c)

- Most students were able to interpret the graphs correctly.

Part (d)

- Most students correctly identified the concentration of the solution but were unable to identify the path length or the molar absorptivity of the solute. Common errors were listing absorbance or % transmittance as a factor and listing wavelength or frequency of light as a factor.

Part (e)

In this part students:

- failed to differentiate between absorbance and transmittance,
- failed to specifically address the effect of the fingerprints on the experimentally determined concentration of the solution, and
- mistakenly believed that, because light was scattered, the absorbance of the solution decreased.

Part (f)

In this part students:

- addressed the question with a discussion of the relative solubilities or ionic character of $CoCl_2$ and NaCl, and
- described a solution of NaCl as clear, rather than colorless, with no further discussion.

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

- Have students perform dilutions to prepare solutions of known concentrations using appropriate volumetric glassware (volumetric flasks, pipets, burets).

- Have students prepare and interpret a calibration curve with a spectrophotometer and interpolate the curve to determine the concentration of a solution of unknown concentration.

- Make sure that students understand not only the mechanics of what they are doing but also the underlying reasons for performing each step in an analytical procedure.

- Make sure that students understand sources of experimental error and how those errors are propagated to their specific effect on the final experimental value.

- Have students practice preparing and interpreting graphs from their collected data.

Question 6

What was the intent of this question?

This is a required essay question with four parts in which students were to explain certain observations in terms of chemical reactions or chemical principles. 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 on this question?

Students did not perform well on this question. Many of their explanations contained incorrect chemical information, were not grounded in chemical principles, were generally incomplete or terse, and did not provide a coherent argument for the observation. In terms of points received, the parts, in order of increasing difficulty, were (a)/(d), (b), and (c). The mean score was 2 out of a possible eight points.

What were common student errors or omissions?

Part (a)
In this part students:

- identified HCl as the predominant acid in acid rain,
- gave CaO or Ca (not Ca^{2+}) as a product,
- gave incorrect formulas and charges for species in the reaction,
- simply stated that an acid-base neutralization reaction occurred, and
- simply repeated the question in slightly different terms.

Part (b)
In this part students:

- began the discussion with an intermolecular forces argument;
- did not understand the concept of boiling (i.e., that it is a change of state and not a chemical reaction);
- related the greater boiling point elevation of NaCl to dipole-dipole forces (compared to the London dispersion forces and hydrogen bonding in the $C_{12}H_{22}O_{11}$ solution);
- discussed the expected boiling points of solid salt and sugar instead of solutions of salt and sugar;
- suggested that the higher melting point of solid salt resulted in a higher boiling point of its solution;
- explained that sugar is a larger molecule that can block the surface better than salt;
- answered Part (b) (i) solely on the basis of colligative properties (i.e., anytime a solute is added to a solvent, the boiling point of the solution will increase);
- explained that increasing the density of the solutions would increase the boiling point; and
- confused increased dissociation of salt with increased solubility.

Part (c)
In this part students:

- stated that an ideal gas has no mass, or that the molecular velocity of an ideal gas is not affected by temperature;
- stated that methane is a polar molecule;
- discussed hydrogen bonding in methane; and
- used either of the following as the basis for the explanation: “methane has weak bonds” or “methane is combustible and will react with oxygen.”

Part (d)
In this part students failed to:

- make it clear what the origin of the water in the water droplets was (implying that the water moved through the glass by osmosis, or that air was converted to liquid water), and
- explicitly discuss that an energy transfer was required (“cooled down” or “condensation” alone was not sufficient).

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?

Make sure students avoid doing the following:

- simply restating the question;
- presenting partial explanations;
- being sloppy with language and formulas;
- interchanging terms (e.g., Ca instead of Ca^{2+}, atom instead of ion or molecule, partial pressure instead of vapor pressure);
- not carefully addressing the question; and
- using only correlations as an explanation (e.g., $\Delta T_b = mK_b$ for all species), rather than detailing the underlying chemical principles.

Teachers should:

- Review the problem issues and misconceptions identified above.
- Require students to write clear and concise explanations of chemical behavior.
- Emphasize that in questions involving two parameters (e.g., intermolecular forces and excluded volume, as in Part [c]), both must be addressed.
- Emphasize that trends, rules, observations, and equations are not in themselves full explanations. For example, "$i = 2$ for NaCl in $\Delta T_b = imK_b$" is *not* an explanation for the larger ΔT_b of NaCl versus sugar; rather, the explanation should include the notion that $i = 2$ is a result of the dissociation of NaCl into two types of particles in solution.
- Emphasize the importance of using correct terminology.
- Emphasize that well-organized, clear answers are more likely to get partial credit than disorganized ones: train students to read their own answers for meaning (i.e., look for bad logic [tautologies], lack of clarity, and needless repetition).
- Emphasize that it is an unnecessary waste of time to rewrite the question.
- Instruct students to construct their answers so as to make reference to all parts of the question in a way readers can understand.
- Avoid generalizations where more details are warranted (e.g., using the terms "acid-base neutralization reaction" or "neutralization reaction" instead of providing necessary details).

Question 7

What was the intent of this question?

This question was designed to test students' knowledge of thermodynamics and kinetics.

How well did students perform on this question?

Students could choose between Question 7 and Question 8. More than two-thirds of the students chose Question 7, and many performed well on it. The mean score for Questions 7 and 8 was 3.12 out of a possible eight points. Scores of 5 and 6 were common, a score of 7 was less common, and a score of 8 was rarely seen. Students scored most of their points in Parts (a), (b), and (c) and had the greatest difficulty in answering Part (d). Students seemed to have a hard time shifting from thermodynamics arguments to the necessary kinetics arguments in Part (d).

What were common student errors or omissions?

Part (a)

- The fact that bond formation is exothermic was often missed, and thus +950 was given as the answer.
- Some students thought the reactant (2 N) was N-N, with a bond energy of 160 kJ mol^{-1}: this resulted in −790 frequently being given as an answer.
- N_2 was often not recognized as having a triple bond, which led to incorrect answers.

Part (b)

Many students earned one or both points in this part.

- Often, they did not earn a point because they failed to talk about the entropy in terms of a decrease in moles, molecules, or particles between reactants and products.
- Students used terms like "four gases made two gases" or "two gases made one gas."
- Many students flipped the sign of $\Delta S°$, stating that a decrease in entropy was positive. If they went ahead and gave a correct argument, they earned the second point.

Part (c)

- Both a high temperature and a low temperature argument were needed to receive the two points in this part of the question. Often, students simply restated the question, referring to the Gibbs free energy equation, $\Delta G° = \Delta H° - T\Delta S°$, without explaining why a negative $\Delta H°$ and a negative $\Delta S°$ result in a change in the sign of $\Delta G°$ as the temperature is increased.
- Some students thought that a low temperature meant a negative T. When this occurred, they could still earn a point for the correct high temperature argument.
- Students who carried forward a $+\Delta S°$ from Part (b) could still earn one point by stating that a small $T\Delta S°$ does not add significantly to $-\Delta H°$, so $\Delta G°$ is negative.
- Many students confused S with $\Delta S°$ and gave arguments that as T increased so did $\Delta S°$. This did not earn points.
- Rather than writing a statement for both high and low temperatures, some students gave the correct answer for one condition (either high or low temperature) and then stated "and vice versa" or "the opposite is true", which often was not a correct statement.
- Many students correctly responded to this problem using a strictly mathematical approach, stating that if $\Delta S°$ was negative, the Gibbs equation could be restated as $\Delta G° = \Delta H° + T\Delta S°$. As temperature increased, the small positive value of this portion of the equation eventually equaled (and then became greater than) the negative value of the enthalpy ($\Delta H°$) of this reaction, which resulted in a positive value for $\Delta G°$.
- Students could earn both points for using the LeChâtelier argument tied to equilibrium and $\Delta G°$. One point was earned for the high temperature argument when students stated that as heat is added, the equilibrium shifts to the left, resulting in a $K < 1$, which would result in a positive $\Delta G°$ for the reaction ($\Delta G° = -RT\ln K$). A second point was earned for a low temperature argument that stated the correct relationship between heat, equilibrium, and free energy. At low temperatures very little heat is produced and $K > 1$, which results in $\Delta G°$ that is less than 0 and thus the reaction is spontaneous. This argument was rarely seen in its entirety.

Part (d)

When points were lost in this question, it was often here.

- Students had a hard time shifting away from thermochemistry. Many tried to tie $\Delta G°$, $\Delta H°$, and $\Delta S°$ with the rate of the reaction. A sense that molecules collide with sufficient energy needed to be given.
- No credit was earned for making such statements as:
  - "The rate is slow",
  - "A catalyst is needed for this reaction to occur",
  - "The gas molecules move slowly", and
  - "Molecules are not moving fast enough" (with no mention of collisions).
- An argument that tied the frequency of collisions and the energy needed to overcome the activation energy for this reaction earned full credit.
- When points were earned, most frequently it was for either the collision theory or the activation energy argument.

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

Students should keep the following in mind:

- Bond breaking requires the addition of energy (+).
- Bond making gives off energy (–).
- Read each part of the question carefully. All parts of a question may not be on the same chemistry topic (as in Part [d]).
- Do simple math correctly.
- There is no need to restate the question in the answer.
- Write darkly with pencil or write with a pen.
- Do not use symbols that are not universal.
- Do not use shorthand (e.g., "bc" for because). Readers may not be familiar with it.

Teachers should:

- Have students practice predicting the outcome of a calculation when variables are changed and then have them explain the result, as in Part (c) of this question.
- Make students write concisely.

Question 8

What was the intent of this question?

This question tested students' chemistry knowledge in the following areas: drawing structural formulas, determining molecular geometries, relating intermolecular forces to the enthalpy of vaporization, and describing a molecular structure using bond theory.

How well did students perform on this question?

Students could choose between Question 7 and Question 8. Question 8 was the less popular of the two optional essays. Approximately 29 percent of the students answered this question. The mean score for Questions 7 and 8 was 3.12 out of a possible eight points. Points were most often earned in Parts (a) (i), (a) (ii), (c), (d) (i), and (d) (ii).

What were common student errors or omissions?

Part (a) (i)

- Surprisingly, many students read the question wrong. Instead of drawing the structural formula for propanone, they drew propane. This was obvious in many instances where they drew the correct structure as part of their answer for Part (b) (i) or Part (b) (ii).

- Most of the students were able to correctly draw the propanone molecule. The mistakes that were made centered around the oxygen atom. The oxygen atom was often placed between two of the carbon atoms or attached to the second carbon atom by only one bond.

Part (a) (ii)

Angles of 90°, 109.5°, 120°, and 180° were common answers. This was an easy point for most students.

- Problems arose when students either incorrectly drew propane or placed the oxygen between the carbon atoms. If propane was drawn, then the correct answer for that bond angle was 109.5°. If the oxygen atom was placed between the carbon atoms, then no angle was possible because the question asked for the carbon-to-carbon-to-carbon bond angle.

Parts (b) (i) and (b) (ii)

These were by far the most difficult parts of this question, and the ones that kept many students from getting a perfect score of 8. Readers found it best to read both Part (b) (i) and Part (b) (ii) before determining how many points were earned.

- Students were asked to explain why propane and propanone differed in their heats of vaporization (which were given). Many students either determined the molar mass of each molecule or determined the number of bonds in each molecule. The molar mass argument by itself was not given credit, and the counting of the number and types of bonds showed that students believed the process of vaporization meant the molecules would be ripped apart into their individual atoms. What was looked for (but rarely seen) was a discussion of intermolecular forces.
- If students did discuss the intermolecular forces, many thought the propanone would form hydrogen bonds. If students clearly stated that the 1-propanol formed hydrogen bonds and this is the reason for the high heat of vaporization, one point may have been earned.
- This was a very difficult section to read. The words students chose often implied *intra*molecular forces. An example of this would be the way some students wrote about the hydrogen bond in 1-propanol. It was very common to see students discuss the strength of the O-H bond.

Part (c)

This part was also difficult for many students.

- Many students incorrectly drew propane. There is no isomer for propane.
- Many students incorrectly placed oxygen between the second and third carbon atoms. This made it almost impossible to earn the isomer point.
- If students did draw propanone correctly in Part (a) (i), many simply flipped the oxygen from the top to the bottom or bent the carbon chain.
- Many students also came up with some very unusual, but correct, isomers.

Part (d) (i)

This was a very easy point for many students. A high percentage were able to correctly identify the *sp* hybridization of the C-C bond in propyne. If students understood the concept of hybridization, it was easy for them to correctly identify which orbitals were involved.

Part (d) (ii)
Many students earned all of their points for Question 8 on this part. While this question seemed easy for most students, two errors commonly arose.

- Students read the question incorrectly. They were to detemine the number of sigma and pi bonds in the *entire* molecule and not just in the atom indicated by the arrow.
- Many students saw the triple bond as 1 sigma and 1 pi bond, or no sigma and 2 pi bonds.

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?

- Encourage students to read questions carefully. Incorrectly doing the structural diagram for propane cost many students valuable points. Also, when asked to determine the number of sigma and pi bonds "in the molecule," many students determined the number for one of the atoms.

- As last year's and this year's exams show, students do not have a good grasp of intermolecular forces. They often cannot determine the forces that are present between molecules, and they confuse the concepts of inter- and intramolecular forces. Time needs to be spent discussing the difference between these two types of forces. Particular emphasis should be placed on the concept of hydrogen bonding. Many students used intermolecular attractive forces to answer Question 6, Part (b) but were unable to recognize that a discussion of intermolecular attractive forces was needed in Question 8, Part (b). Students may need more practice recognizing when to use intermolecular attractive forces as the basis of their argument.

- As always, teachers need to be very picky about their word usage in the classroom and the selection of words and phrases their students use in their lab write-ups and their essays.