

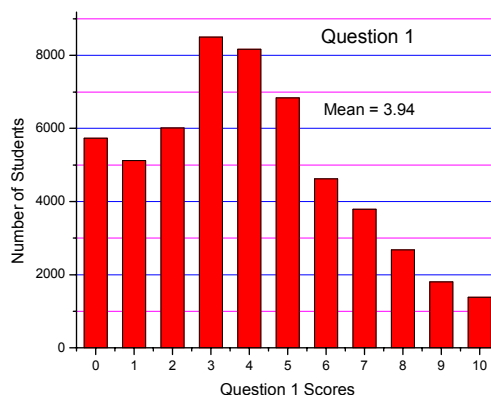


## Student Performance Q&A: 2001 AP<sup>®</sup> Chemistry Free-Response Questions

The following comments are provided by the Chief Faculty Consultant regarding the 2001 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 Exam.* 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

The traditional “equilibrium” problem dealt with the solubility and the  $K_{sp}$  values of  $\text{AgCl}(s)$  and  $\text{PbCl}_2(s)$ . The histogram below shows that the mode was 3 (out of 10 possible points) with an arithmetic mean of 3.94 points.



Common errors on Question 1 included:

#### Part (a)

- Many wrote the “equation for the dissociation of  $\text{AgCl}(s)$ ” as a double replacement reaction. (“ $\text{AgCl} + \text{HOH} \rightarrow \text{AgOH} + \text{HCl}$ ”)
- Many were unable to use the solubility information, from part (a) (ii), to calculate a  $K_{sp}$

## Part (b)

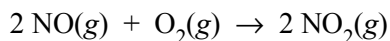
- Students frequently misinterpreted the relative magnitudes of numbers involving negative exponents. (Which is larger,  $1 \times 10^{-6}$ , or  $1 \times 10^{-5}$ ?)
- The squared term was often omitted in the  $K_{sp}$  for  $\text{PbCl}_2$ . ( $K_{sp} = [\text{Pb}^{2+}][\text{Cl}^-]^2$ )
- Part (b) (iii), dealing with selective solubilities, was most frequently omitted. When attempted, students often simply compared  $K_{sp}$  values, rather than comparing the  $[\text{Cl}^-]$  needed to induce precipitation. This was the most poorly understood part of the question.

## General comments on Question 1:

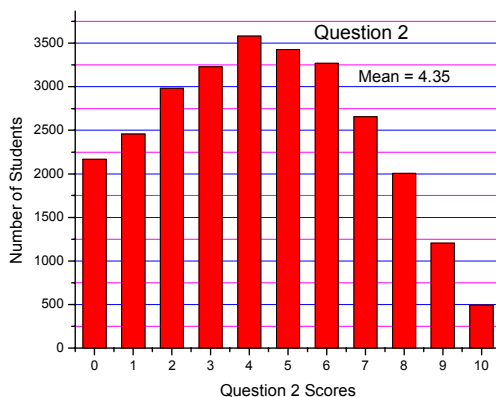
Many students indicated that they had not ever seen “ $K_{sp}$ ’s”. This is an important part of the equilibrium section in the AP curriculum, and should not be neglected. Emphasis should be placed on selected solubility concepts, as probed in part (b) (iii), and on questions such as “would a precipitate form under these conditions?”.

## Question 2

Question 2 focused on energy calculations in the chemical reaction



The mean score was 4.35 out of 10 points, and the histogram showed a good spread of student scores. This was an optional problem; students were asked to do either Question 2 *or* Question 3. About half of the students chose Question 2.



Part (a) required the calculation of heat released from the reaction of a given mass of NO. Students could generally calculate the moles of the reactant involved in the reaction, but were often unable to calculate the quantity of heat released. The most common error was not recognizing that the  $\Delta H$  was the enthalpy change for the reaction of 2 moles of NO. Rather than answer the question asked, and say that “139 kJ of heat was released,” many wrote simply “ $\Delta H = -139 \text{ kJ}$ ”; this is a true statement, but does not answer the question asked.

In part (b) (i), the value of  $\Delta G^\circ$  was given, and the students were asked to calculate the equilibrium constant. Students had difficulty keeping the units consistent (e.g.,  $R$  in  $\text{J/K} \times \text{mole}$  and  $\Delta G^\circ$  in joules) and with the math involved in calculating  $K$  from  $\ln K$ .

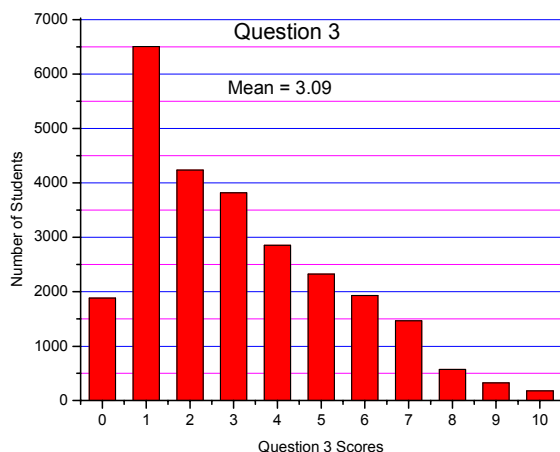
Part (b) (ii) required students to qualitatively predict the effect of a temperature increase on the value of  $\Delta G^\circ$ . A correct answer required the proper interpretation of “ $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ ”, with the answer hinging on the sign of the  $\Delta S^\circ$  term (it is negative for this reaction). A commonly seen error involved an answer that focused on the sign of  $\Delta H^\circ$ ; e.g., “since it is an endothermic reaction, increasing the temperature shifts the reaction to the left”. This may be a true statement (if the reaction system is at equilibrium), but such an analysis does not address the question concerning the effect of changing temperature on the value of  $\Delta G^\circ$ .

The most common error in part (c) involved setting up calculations as if calculating  $\Delta S^\circ$  for the reaction, confusing products and reactants.

Many students approached part (d) as a Hess’ Law problem involving enthalpy of formations, rather than bond energies. Another common mistake was using the equation coefficient 2, rather than 4, the number of bonds created when two molecules of  $\text{NO}_2$  are formed.

### Question 3

The histogram for Question 3, the second of the optional problems, showed a mode at 1 point, with an arithmetic mean of 3.09 (out of 10 possible points).



Part (a) provided an accessible entry, testing the ability to convert units and determine a mass percent from given data. In part (b), students needed to use data to determine the elemental composition of a sample, and to demonstrate their understanding of stoichiometry, the Ideal Gas Law, and conservation of mass. Part (c) required students to use given titration data to determine the molar mass of an acid, while part (d) presented pH data for a second titration, and asked the students to determine the  $K_a$  of the weak acid and the pH of the solution at a given point past the equivalence point.

Common errors on Question 3 included:

Part (b):

- Partial responses, with answers left as moles or as a mole ratio
- Assuming STP, and incorrectly determining moles of  $\text{CO}_2$  by dividing volume by 22.4 L/mole
- Failure to recognize that  $\text{O}_2(g)$  is a reactant during combustion, which leads to...
- Failure to obtain the mass of oxygen in the unknown by difference, and reporting the mass of oxygen in the unknown as the sum of the masses of oxygen in both products
- Failure to recognize the significance of their calculated value for the moles of  $\text{CO}_2$  produced. Many students, given  $P$ ,  $V$ , and  $T$  data, applied the Ideal Gas Law, but failed to recognize the significance of the value obtained.

Part (c):

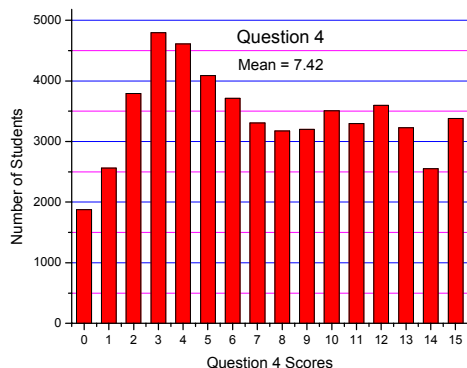
- Failure to convert volume of base from mL to L

Part (d):

- Failure to distinguish between the equivalence point and the  $\frac{1}{2}$ -equivalence point
- Failure to recognize that the pH after the equivalence point is determined by the concentration of excess  $\text{OH}^-$  ion present
- Failure to account for the dilution of the  $\text{OH}^-$  ion as solutions were added

## Question 4

Question 4 was the traditional “reactions” question. A chemical situation is described (e.g., “sulfur dioxide gas is bubbled into distilled water,” or “powdered magnesium carbonate is heated strongly”, etc.), and the students are asked to give the chemical symbols for the reactants as well as the resulting products. Student performance on this year’s question (15 points maximum) produced a histogram that was relatively flat from 6 to 15 points, with the mode at 3 and the arithmetic mean at 7.42 points.

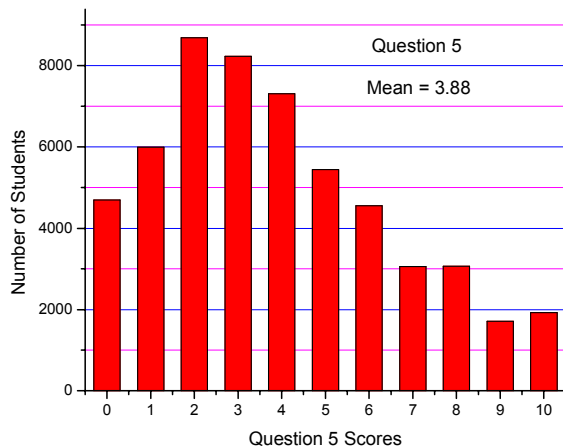


Common errors on Question 4 included:

- Failure to write soluble ionic compounds as ions. “Aqueous hydrochloric acid” should be represented as “ $\text{H}^+ + \text{Cl}^-$ ” not as “ $\text{HCl}$ ”
- Not knowing symbols, formulas, and/or charges for fundamental ions such as iron(III), silver, potassium, strontium, magnesium, nitrate, chloride, bromide, sulfate, carbonate, and dichromate
- Not knowing the solubility rules for nitrates, sulfates, chlorides, and bromides
- Failure to omit spectator ions in a net ionic equation
- Failure to recognize sulfur dioxide as an acidic oxide
- Writing  $\text{Cu}^+$  and  $\text{Ag}^{2+}$  as stable ions in aqueous solution
- Failure to recognize that potassium propionate is an ionic compound
- Failure to write elemental halogens as diatomic molecules
- Failure to recognize dichromate as an oxidizing agent, and that the reaction of iron(II) with dichromate is an oxidation-reduction reaction
- Not writing both an oxidized and a reduced species in oxidation-reduction reactions

### Question 5

This question is similar to an optional essay question that was on the 1999 AP Chemistry Examination; it was written and selected by the members of the Development Committee because it probes many different aspects of aqueous solutions. The mode was 2 (out of a maximum of 10 points) with an arithmetic mean of 3.88 points.



Common wrong answers on Question 5 included:

Part (a):

- $\text{Pb}(\text{NO}_3)_2$  must have the highest boiling point, because
  - it is the heaviest (most massive), or most dense
  - it has the most atoms
  - it breaks into the greatest number of molecules
  - $\text{Pb}^{2+}$  had the largest lattice energy (divalent)
- According to LeChatelier’s principle...

- $\text{C}_2\text{H}_5\text{OH}$  (or  $\text{KC}_2\text{H}_3\text{O}_2$ ), because it has the largest number of hydrogen atoms (or hydrogen bonds)
- $\text{KMnO}_4$  is the one with the most oxygens to burn

Part (b):

The obvious distracter was solution 4 ( $\text{C}_2\text{H}_5\text{OH}$ ), and the majority of students chose it. Students need to recognize simple organic compounds such as alcohols and acids, and be aware of their behavior in solution. Many said the solution was basic due to  $\text{OH}^-$  but just as many said it was acidic because of all the hydrogens.

Other common errors included:

- $\text{KMnO}_4$  because it is colored (because it turns litmus blue — it was shown as a colored solution)
- All have the same pH since they are all 0.1 *M* solutions

Part (c):

This section revealed that the solubility rules are not well understood.

Common wrong answers included:

- No precipitate was indicated
- $\text{NaNO}_3$  was often listed as the precipitate
- Incorrect stoichiometry for lead chloride (“ $\text{PbCl}$ ”, rather than “ $\text{PbCl}_2$ ”)

Part (d):

Many students knew what oxidation was, and correctly identified the oxidation product as  $\text{Cl}_2$ , but could not figure out which solution could cause the oxidation. It is difficult to cover electrochemistry extensively before the AP Exam, but the minimum AP coverage should include descriptions of redox reactions (oxidation numbers, half-reactions, and oxidizing/reducing agents).

Common errors included:

- Identifying the oxidation product as  $\text{Cl}$  (or  $\text{Cl}^0$ ), not  $\text{Cl}_2$
- Identifying  $\text{Mn}^{2+}$  as the oxidation product
- Apparently confusing parts (c) and (d).  $\text{Pb}(\text{NO}_3)_2$  was commonly cited as the oxidizing agent, with  $\text{PbCl}_2$  as the oxidation product.

Part (e):

Common errors included:

C<sub>2</sub>H<sub>5</sub>OH (the correct choice), because

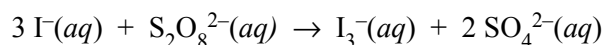
- it is the least soluble
- it is the least electronegative (or is nonpolar)
- it does not produce any positive anions
- it does not have any metal atoms in its formula. Metals are good conductors.
- it is the most basic
- it has many electrons
- it is organic (or is an alcohol)
- it is composed of gases

Other common misconceptions included:

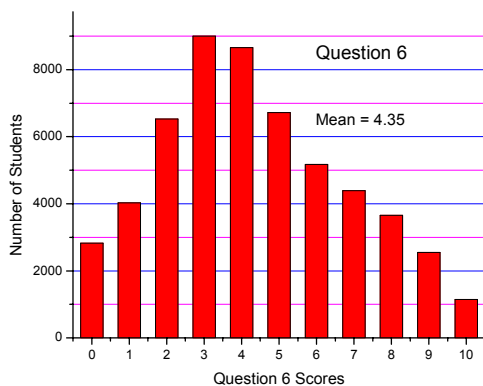
- KMnO<sub>4</sub> is the worst conductor because it is the only colored solution
- If a solution is soluble it must break into ions
- To be a conductor, there must be free mobile electrons

## Question 6

Question 6 asked about several aspects of the aqueous oxidation of iodide ion by peroxydisulfate ion



Students were given the balanced chemical equation and some graphical experimental data showing the concentration of a product (triiodide ion) as a function of time. The question asked about the reaction, about how to obtain information from the graph and how to use this information to determine theoretical parameters for the kinetics of the reaction. The mode was 3 (out of 10 possible points) with an arithmetic mean of 4.35 points.



Common errors on Question 6 included:

Part (a):

- Referring to this redox reaction as a “disproportionation”
- Failure to write the formula of an oxidizing agent. Many suggested  $\text{SO}_4^{2-}$  as an alternative oxidizing agent, even though sulfate was a product of the reaction

Part (b):

- Determining the instantaneous rate at 20 minutes by dividing the concentration reached at 20 minutes by the 20 minutes of elapsed time
- Some appeared to believe that the left axis of the graph was already a rate, or that the slope of the line was the rate constant rather than the rate of formation of product

Parts (c) and (d):

- The major difficulty was the lack of clarity in the responses. Many answers made vague references to a “change the concentrations,” but were not specific about the precise changes they would make. Due to imprecise and confusing explanations, it was often very difficult to determine whether the student understood the chemistry.

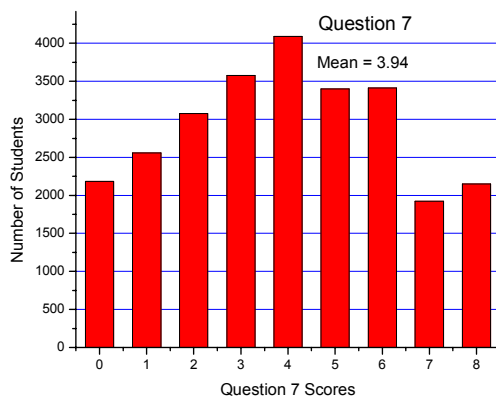
General comments on Question 6:

- Students should recognize a redox reaction, and know a few common oxidizing (and reducing) agents.
- Students need to be able to interpret information in a graph, being careful to recognize what the axes represent, what slopes mean, how this corresponds to rates of change, etc.
- Stoichiometry is always important, and reactions that go to completion must have very large equilibrium constants, so that the ‘back reaction’ must not be very important.
- Details are important; formulae must be correct, including charges on ions.
- Teachers should work to hone (or uncover) each student’s ability to use written English prose to explain experimental design and/or experimental results.



## Question 7

Question 7 was one of the two optional essays (students were to do either Question 7 *or* Question 8); about 50 percent of the students chose Question 7. The question probed the students' understanding of the chemistry occurring in a galvanic cell. The mode was 4 (out of 8 possible points), with an arithmetic mean of 3.94 points.

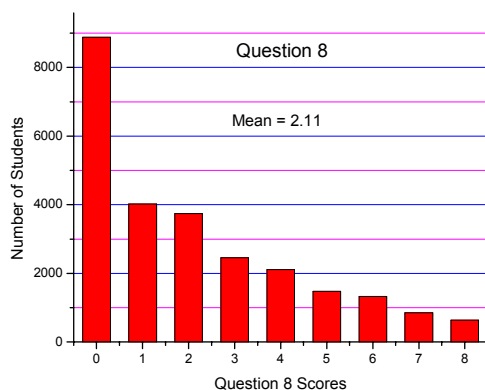


Common errors on Question 7 included:

- Many incorrectly identified Ni as the anode as it was the cell on the left side of the figure. (Identification of the anode does not depend on which side of the lab bench one is standing on.)
- Many had difficulty qualitatively reasoning with negative numbers, particularly double negatives, and numbers in logs.
- In identifying the effect of a decrease in reactant concentration on  $E_{cell}$ , many did use the Nernst equation, but reasoned that  $Q$  had decreased, not increased.
- Some interpreted a concentration change as a change in the “ $n$ ” term in the Nernst equation.
- Some calculated  $K$  using *initial* reactant and product concentrations.

## Question 8

Question 8 (an optional essay paired with Question 7) probed the students' understanding of intermolecular interactions; the results were disappointing. About half of the students chose this question, but for students who had not studied electrochemistry, it was their better option. Since intermolecular interactions are studied in both the first chemistry course and in the AP Chemistry course, the manifest confusion between *inter* and *intramolecular* forces was not anticipated. The mode for Question 8 was 0, and the arithmetic mean was 2.11 (out of 8 possible points).



Common errors on Question 8 included:

Overall:

- Failure to discuss **both** substances. The question included the statement “your answer must include references to **both** substances,” yet it was common for only one of the two materials in each part to be discussed.
- Many students consistently confused *inter*- and *intramolecular* interactions.

Part (a):

- Confusing hydrogen-bonding (an intermolecular force) with the intramolecular N-H covalent bonds within the ammonia molecule
- Failure to identify the type of intermolecular force between CH<sub>4</sub> molecules
- Identifying NH<sub>3</sub> as polar (and perhaps CH<sub>4</sub> as nonpolar) but then not acknowledging the existence of, or discussing, the resulting intermolecular forces. Structure arguments are a good start, but they must then lead to a discussion of intermolecular forces.
- Believing that boiling requires breaking of covalent bonds
- Stating that hydrogen bonding between ammonia molecules is stronger than covalent bonding within methane molecules

Part (b):

- Not recognizing that the physical state of a substance at a given temperature is related to the intermolecular forces between the molecules
- Thinking that greater “weight” means greater London Dispersion Forces
- Believing that  $C_6H_{14}$  has more hydrogen bonds than  $C_2H_6$  or that  $C_6H_{14}$  has more bonds to break than  $C_2H_6$

Part (c):

- Attributing metallic bonding to Si, and/or ignoring the intermolecular forces in  $Cl_2$
- Proposing that  $Cl_2$  has a weak covalent bond as opposed to the strong covalent bond in Si
- Stating that  $Cl_2$  is a gas and therefore has a low melting point and that Si is a solid so it has a high melting point

Part (d):

- Using electronegativity difference as a reason
- Declaring one substance to be ionic while the other is covalent
- Claiming that MgO contains a double bond while NaF contains a single bond
- Suggesting that Mg shares 2 electrons with O, while Na shares only 1 electron with F

General comments on Question 8:

- It is important to stress the difference between the attractions within a molecule (*intramolecular* attractions — generally referred to as “bonding”) and the *intermolecular* forces between molecules.
- It is important to emphasize that when a material undergoes a phase change, only the *intermolecular* attractions are affected; when  $NH_3$  boils, the N-H bonds within the  $NH_3$  molecule are not cleaved.
- The distinction between **atoms** and **molecules** is crucial; the terms are not interchangeable.

Teaching tips for Question 8:

- Use the question prompt as a structure for the answer. It would also be helpful to make a table of information like the one below.

<b>Compound</b>	<b>Chemical Bond</b>	<b>Relative Strength of Bond</b>	<b>IMF</b>	<b>Relative Strength of IMF</b>
<b>#1</b>				
<b>#2</b>				

The student should list the information and then explain the differences based on strength of bonding and/or IMF. This chart may help the student organize all information and not leave out key points in the answer. A clear, concise answer is always preferred.

- Stress to students the difference between bonding (intramolecular) and intermolecular forces.
- Take time to relate physical properties to both bonding and intermolecular forces.
- Try using the term “hydrogen bridging/attraction” instead of hydrogen bonding.
- Make very clear the distinction between *atoms* and *molecules* and why the terms are not interchangeable.