AP Chemistry
2001 Scoring Guidelines

The materials included in these files are intended for non-commercial use by AP teachers for course and exam preparation; permission for any other use must be sought from the Advanced Placement Program. Teachers may reproduce them, in whole or in part, in limited quantities, for face-to-face teaching purposes but may not mass distribute the materials, electronically or otherwise. These materials and any copies made of them may not be resold, and the copyright notices must be retained as they appear here. This permission does not apply to any third-party copyrights contained herein.

These materials were produced by Educational Testing Service (ETS), which develops and administers the examinations of the Advanced Placement Program for the College Board. The College Board and Educational Testing Service (ETS) are dedicated to the principle of equal opportunity, and their programs, services, and employment policies are guided by that principle.

The College Board is a national nonprofit membership association dedicated to preparing, inspiring, and connecting students to college and opportunity. Founded in 1900, the association is composed of more than 3,900 schools, colleges, universities, and other educational organizations. Each year, the College Board serves over three million students and their parents, 22,000 high schools, and 3,500 colleges, through major programs and services in college admission, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT™, the Advanced Placement Program® (AP®), and Pacesetter®. The College Board is committed to the principles of equity and excellence, and that commitment is embodied in all of its programs, services, activities, and concerns.

Copyright © 2001 by College Entrance Examination Board. All rights reserved. College Board, Advanced Placement Program, AP, and the acorn logo are registered trademarks of the College Entrance Examination Board.

Question 1

(10 points)

(a) (i) $AgCl(s) \rightarrow Ag^+(aq) + Cl^-(aq)$ ***1 point***

- Correct charges needed to earn credit.
- Phases not necessary to earn credit.

(ii) $\dfrac{8.9 \times 10^{-5}\ g}{143.32\ \text{g/mol}} = 6.2 \times 10^{-7}$ mol (in 100 mL) ***1 point***

$(6.2 \times 10^{-7}$ mol/100 mL) (1,000 mL/1.000 L) = **6.2 ´ 10^{-6} mol/L** ***1 point***

Note: The first point is earned for the correct number of moles; the second point is earned for the conversion from moles to molarity.

(iii) $K_{sp} = [Ag^+][Cl^-] = (6.2 \times 10^{-6})^2$ = **3.8 ´ 10^{-11}** ***1 point***

Note: Students earn one point for squaring their result for molarity in (a) (ii).

(b) (i) n_{Cl^-} = (0.060 L) (0.040 mol/L) = 0.0024 mol ***1 point***

$[Cl^-]$ = (0.0024 mol)/(0.120 L) = 0.020 mol/L = **0.020 *M***

$n_{Pb^{2+}}$ = (0.060 L) (0.030 mol/L) = 0.0018 mol

$[Pb^{2+}]$ = (0.0018 mol)/(0.120 L) = 0.015 mol/L = **0.015 *M***

$Q = [Pb^{2+}][Cl^-]^2 = (0.015)(0.020)^2$ = **6.0 ´ 10^{-6}** ***1 point***

$Q < K_{sp}$, therefore no precipitate forms ***1 point***

Note: One point is earned for calculating the correct molarities; one point is earned for calculating Q; one point is earned for determining whether or not a precipitate will form.

(ii) $[Pb^{2+}] = \dfrac{K_{sp}}{[Cl^-]^2} = \dfrac{1.6\times10^{-5}}{(0.25)^2}$ = **2.6 ´ 10^{-4} *M*** ***1 point***

Question 1 (cont.)

(iii) for AgCl solution: $[\mathrm{Cl^-}] = \dfrac{K_{sp}^{\mathrm{AgCl}}}{[\mathrm{Ag^+}]} = \dfrac{1.8 \times 10^{-10}}{0.120} = \mathbf{1.5 \times 10^{-9}}\ \boldsymbol{M}$ ***1 point***

for $PbCl_2$ solution: $[\mathrm{Cl^-}] = \sqrt{\dfrac{K_{sp}^{\mathrm{PbCl_2}}}{[\mathrm{Pb^{2+}}]}} = \sqrt{\dfrac{1.6 \times 10^{-5}}{0.150}} = \mathbf{1.0 \times 10^{-2}}\ \boldsymbol{M}$

The $[\mathrm{Cl^-}]$ will reach a concentration of 1.5×10^{-9} *M* before it reaches a concentration of 1.0×10^{-2} *M*, (or $1.5 \times 10^{-9} << 1.0 \times 10^{-2}$), therefore AgCl(*s*) will precipitate first. ***1 point***

Note: One point is earned for calculating $[\mathrm{Cl^-}]$ in saturated solutions with the appropriate Ag^+ and Pb^{2+} concentrations; one point is earned for concluding which salt will precipitate first, based on the student's calculations.

Question 2

(10 points)

(a) $\dfrac{73.1\,\text{g}}{30.01\,\text{g/mol}} = \mathbf{2.44\ mol\ \ NO}$ *1 point*

$2.44\ \text{mol NO} \times \dfrac{114.1\,\text{kJ}}{2\,\text{mol NO}} = \mathbf{139\ kJ\ released}$ *1 point*

Note: The first point is earned for calculating the number of moles of NO involved; the second point is earned for the correct answer with the correct units.

(b) (i) $K = e^{-\Delta G/RT} = e^{(70{,}400\text{ J})/(8.314\text{ J mol}^{-1}\text{ K}^{-1})(298\text{ K})} = \boldsymbol{e^{28.4}} = \mathbf{2.2}$ ´ $\mathbf{10^{12}}$ *2 points*

Note: The first point is earned for using correct (and consistent) values of $\Delta G°$, R, and T; the second point is earned for the correct equation and appropriate math. No penalty if student starts with the equation $\Delta G = -RT \ln \mathrm{K}$ and follows through correctly.

(ii) $\Delta G° = \Delta H° - T\Delta S°$ *1 point*

As the temperature increases, $T\Delta S°$ will decrease ($\Delta S°$ is negative), $-T\Delta S°$ will increase, therefore $\Delta G°$ will become less negative. *1 point*

Note: The first point is earned for using $\Delta G° = \Delta H° - T\Delta S°$, and the second point is earned for the discussion and the correct conclusion. Students should focus on the sign of the $\Delta S°$ term. One point can be earned for a response discussing spontaneity with reference to $\Delta H°$, although this is not entirely correct because K is temperature-dependent. (Since $\Delta H°$ is negative, increasing the temperature sends the reaction to the left, therefore the reaction is less spontaneous, therefore $\Delta G°$ must be getting more positive.)

(c) $\Delta S°_{rxn} = \Delta S_f^{\text{products}} - \Delta S_f^{\text{reactants}} = 2(S^{\mathrm{NO_2}}) - [2(S^{\mathrm{NO}}) + S^{\mathrm{O_2}}]$ *1 point*

$-146.5\ \text{J K}^{-1} = 2(240.1)\ \text{J K}^{-1} - [2(210.8)\ \text{J K}^{-1} + S^{\mathrm{O_2}}]$

$S^{\mathrm{O_2}} = \mathbf{205.1\ J\ K^{-1}} =$ standard molar entropy of O_2 *1 point*

Note: The first point is earned for correctly using the equation $\Delta S°_{rxn} = \Delta S_f^{\text{products}} - \Delta S_f^{\text{reactants}}$ with the correct coefficients from the reaction equation. (All four terms must be in the correct position in the equation.) The second point is earned for calculating the correct answer.

Question 2 (cont.)

(d) ΔH_{rxn} = enthalpy of bonds broken − enthalpy of bonds formed

ΔH_{rxn} = [2(N$\equiv$O) + O=O] − 4[N=O] ***1 point***

−114.1 kJ = [2(607) + 495] kJ − 4 moles [N=O]

N=O bond energy = 456 kJ mol^{-1} ***1 point***

- One point can be earned if the student does problem correctly except for indicating that only two N=O bonds form.
- One point can be earned if the initial equation is reversed, but the rest of the problem is done correctly.

Question 3

(10 points)

(a) $(0.325\text{ g}/2.00\text{ g}) \times 100\% = \mathbf{16.2\%}$ *1 point*

(b) $\frac{1.200\text{ g } H_2O}{18.02\text{ g/mol}} = 0.06659\text{ mol } H_2O$

$(0.06659\text{ mol } H_2O)\,(2\text{ mol H /mol } H_2O) = 0.1332\text{ mol H}$
$(0.1332\text{ mol H})(1.008\text{ g/mol H}) = \mathbf{0.1343\text{ g H}}$ *1 point*

$n_{CO_2} = \frac{PV}{RT} = \frac{(750/760)\text{ atm} \times 3.72\text{ L}}{(0.0821\text{ L atm mol}^{-1}\text{ K}^{-1})\,(298\text{ K})} = \mathbf{0.150\text{ mol } CO_2}$ *1 point*

$(0.150\text{ mol } CO_2)(1\text{ mol C /mol } CO_2) = 0.150\text{ mol C}$

$(0.150\text{ mol C})\,(12.0\text{ g/mol}) = \mathbf{1.80\text{ g C}}$ *1 point*

grams of oxygen = 3.00 g − (1.80 g + 0.133 g) = **1.07 g O** *1 point*

Note: The first point is earned for getting the correct mass of H : the second point is earned for using the Ideal Gas Law and substituting consistent values of *P, V*, *R*, and *T*. The third point is earned for converting moles of CO_2 to moles of C and then grams of C. If the number of moles of CO_2 is calculated incorrectly, but that incorrect value is used correctly, the third point is earned. The fourth point is earned for using the values of H and C to get the mass of oxygen by difference. If one (or both) of the previously determined values is incorrect, but the student uses those incorrect values correctly, the fourth point is still earned.

(c) moles OH^- = (0.08843 L) (0.102 mol/L) = 0.00902 mol OH^-, *1 point*

therefore, 0.00902 mol H^+ neutralized, therefore 0.00902 mole acid

molar mass = $\frac{1.625\text{ g}}{0.00902\text{ mol}}$ = 180. g/mol *1 point*

Note: The first point is earned for setting up the calculation to determine the number of moles of OH^- used in the titration; the second point is earned for using the number of moles of OH^- correctly to get the molar mass. If the number of moles of OH^- is incorrectly calculated, credit can be earned for this step if the student uses the incorrect value correctly.

Question 3 (cont.)

(d) (i) The pK_a is equal to the pH halfway to the equivalence point. ***1 point***

At 10.00 mL of added NaOH, pH = 3.44, therefore pK_a = 3.44

$K_a = 10^{-3.44} = 3.6 \times 10^{-4}$

- Other paths to the correct answer include using the initial data point and the acid equilibrium value, or using the Henderson-Hasselbalch equation

(ii) Beyond the end point, there is excess OH^-, and the $[OH^-]$ determines the pH. ***1 point***

Moles of excess OH^- = (0.00500 L) (0.100 mol/L) = 5.00×10^{-4} mol OH^-

$$[OH^-] = \frac{5.00 \times 10^{-4} \text{ mol } OH^-}{0.04000 \text{ L}} = 1.25 \times 10^{-2}\, M \ OH^-$$

pOH = 1.90

pH = **12.10** ***1 point***

<u>Note:</u> The first point is earned for recognizing that the pH past the end point is determined by the amount of excess OH^- ions; the second point is earned for the calculations and the final answer.

AP® CHEMISTRY
2001 SCORING GUIDELINES

Question 4

(15 points)

Students choose five of the eight reactions. Only the answers in the boxes are graded (unless clearly marked otherwise). Each correct answer earns 3 points; 1 point for reactants and 2 points for products. Reactants must be completely correct to earn the reactant point. All products must be correct to earn both product points; one of the two products correct earns 1 product point. Equations need not be balanced nor phases indicated (and no penalty if present but incorrect). Any spectator ions on the reactant side nullify the 1 possible reactant point, but if they appear again on the product side, there is no product-point penalty. Ion charges must be correct.

(a) $SO_2 + H_2O \rightarrow H^+ + HSO_3^-$
(***or*** $SO_2 + H_2O \rightarrow H_3O^+ + HSO_3^-$, ***or*** $SO_2 + H_2O \rightarrow H_2SO_3$)

- 1 product point earned for "$H^+ + SO_3^{2-}$"

(b) $Fe^{3+} + SCN^- \rightarrow [Fe(SCN)]^{2+}$ (***or*** $[Fe(SCN)(H_2O)_5]^{2+}$ ***or*** $[Fe(SCN)(H_2O)_3]^{2+}$)

- Credit can be earned for any number of coordinated SCN^- ions from 1 through 6.
- For full credit, charges must be correct (square brackets not required).
- 1 product point earned if only product error is wrong charge.

(c) $Cu + Ag^+ \rightarrow Cu^{2+} + Ag$

- 1 product point earned for "$Cu^+ + Ag$"

(d) $C_2H_5COOH + OH^- \rightarrow C_2H_5COO^- + H_2O$

- Other correct formulas for propanoic acid, including structural formulas, are also accepted.

(e) $Fe^{2+} + Cr_2O_7^{2-} + H^+ \rightarrow Fe^{3+} + Cr^{3+} + H_2O$

- 2 product points but no reactant point earned for "$Fe^{2+} + Cr_2O_7^{2-} \rightarrow Fe^{3+} + Cr^{3+}$"

(f) $Cl_2 + Br^- \rightarrow Cl^- + Br_2$

(g) $Sr^{2+} + SO_4^{2-} \rightarrow SrSO_4$

(h) $MgCO_3 \rightarrow MgO + CO_2$

- 1 product point earned for "$Mg + CO_2$"

Question 5

(10 points)

In each part, one point is earned for the correct solution or solutions, and one point is earned for the correct explanation (in parts a, b, and e), precipitate (in part c), or product (in part d).

(a)	$Pb(NO_3)_2$ (Solution 1)	***1 point***
	$Pb(NO_3)_2$ has the largest value of i, the van't Hoff factor, so the solution has the highest number of solute particles (it dissociates into the most particles).	***1 point***
	• Student must address the relative number of particles.	
(b)	$KC_2H_3O_2$ (Solution 5)	***1 point***
	The acetate ion is the conjugate base of a weak acid, so it is a weak base (***or*** $KC_2H_3O_2$ is the salt of a strong base and a weak acid, so the solution is basic).	***1 point***
(c)	$Pb(NO_3)_2$ and NaCl (Solutions 1 and 2)	***1 point***
	$PbCl_2$ would precipitate	***1 point***
	• Points can also be earned for $KMnO_4$ plus one of the other solutions (with the precipitation of MnO_2). • Points can also be earned for $KMnO_4$ plus $Pb(NO_3)_2$ (with the precipitation of PbO_2, or MnO_2).	
(d)	$KMnO_4$ (Solution 3)	***1 point***
	The product of the oxidation is Cl_2	***1 point***
(e)	C_2H_5OH (Solution 4)	***1 point***
	Ethanol is the only nonelectrolyte given. It does not readily dissociate into ions, so it would not produce charged species that would conduct a current.	***1 point***
	• One point can also be earned for explanations using i, the van't Hoff factor.	

Question 6

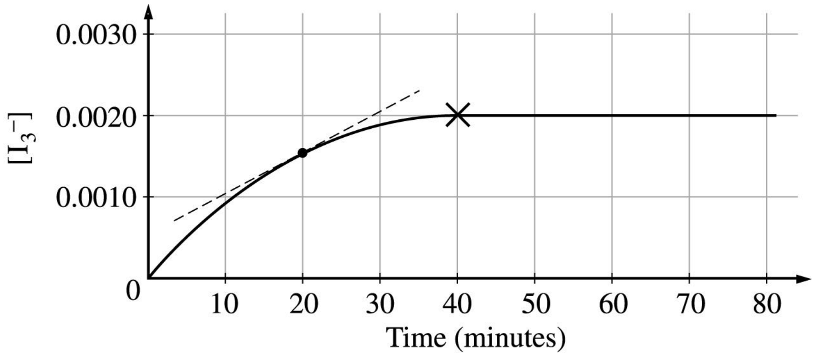
(10 points)

(a) The reaction is an oxidation-reduction (redox) reaction. ***1 point***

To go from I^- to I_3^-, the iodine has to be oxidized, so credit is earned for the formula of any reasonable oxidizing agent (e.g., F_2, Co^{3+}, O_2, MnO_4^-) ***1 point***

(b) (i) One point is earned for an "X" drawn on the curve at a point corresponding to approximately 37-42 minutes (see graph below). This is where the curve levels off. ***1 point***

(ii) The instantaneous rate of the reaction at 20 minutes is the slope of the line tangent to the curve at 20 minutes. (See the graph below.) ***1 point***



- No credit is earned if the student confuses "rate" with "rate constant".

(b) Keep the initial concentration of $S_2O_8^{2-}$ constant, change the initial concentration of I^- by a known amount, and see what effect this change has on the measured rate of the reaction. This procedure should be repeated, but this time keeping the concentration of I^- constant and changing the concentration of $S_2O_8^{2-}$. ***2 points***

Note: Points are earned for a method that involves controlling one reactant concentration and varying the other while comparing the reaction rates.

- No credit is earned if student confuses product and reactant concentrations.

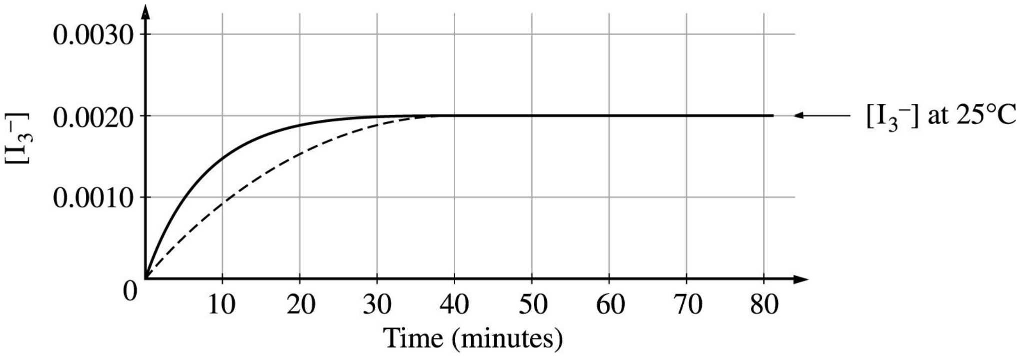
Question 6 (cont.)

(d) The general rate law expression is: rate $= k[\text{I}^-]^x[\text{S}_2\text{O}_8^{2-}]^y$ ***1 point***

The values of x and y can be determined by the experiments described in (c) above. These values can then be put into the equation with the rate and concentrations at a particular time in a particular trial, and the equation can then be solved for k. ***1 point***

- No credit is earned if student confuses rate law with equilibrium expression.
- No credit is earned if student uses reverse reaction expression.

(e) On the graph, a curve is drawn that starts at the origin, rises more quickly than the original curve, and levels off at $[\text{I}_3^-] = 0.0020\ M$. (See example drawn on the graph below.) ***2 points***



Note: One point is earned if the curve starts at the origin and rises more quickly than the original curve; the other point is earned if the curve levels off at the same $[\text{I}_3^-]$ as the original curve.

AP® CHEMISTRY
2001 SCORING GUIDELINES

Question 7

(8 points)

(a) The anode is the electrode on the right (Zn is the anode) ***1 point***

- Point is also earned if the student points to the Zn cell in the diagram.

The half-reaction is $Zn \rightarrow Zn^{2+} + 2\,e^-$ ***1 point***

(b) $Zn + Ni^{2+} \rightarrow Zn^{2+} + Ni$ ***1 point***

$E^\circ_{cell} = (-0.25\text{ V}) - (-0.76\text{ V}) = \mathbf{0.51\text{ V}}$ ***1 point***

- Some work must be shown to support the answer.

(c) E_{cell} would decrease ***1 point***

Since Ni^{2+} is a reactant, a decrease in its concentration decreases the driving force for the forward reaction ***1 point***

or

$$E_{cell} = E^\circ - \frac{RT}{n\wedge}\ln Q, \text{ where } Q = \frac{[Zn^{2+}]}{[Ni^{2+}]}$$

Decreasing the $[Ni^{2+}]$ would increase the value of Q, so a larger number would be subtracted from E°, thus decreasing the value of E_{cell}.

(d) $K > 1$ ***1 point***

E° is positive, so $K > 1$ ***1 point***

<u>Note:</u> The student's score in part (d) is based on the sign of E°_{cell} calculated in part (b).

<u>Note on Overall Question:</u> If in part (a) a student incorrectly identifies Ni as being oxidized, partial credit is earned if subsequent parts are followed through consistently.

AP® CHEMISTRY
2001 SCORING GUIDELINES

Question 8

(8 points)

For each part, the student earns credit by indicating what kind of bonding and/or intermolecular forces are present, and giving some information about their relative strengths. The student can earn one point for giving the correct type of bonding and/or intermolecular forces present in <u>both</u> of the species in any part.

(a) NH_3 has hydrogen bonding between molecules (***or*** dipole-dipole interactions between molecules), and CH_4 has London dispersion forces. The intermolecular forces in NH_3 are stronger than those in CH_4. ***2 points***

- No credit earned for only a discussion of lone pairs of electrons.
- No credit earned for saying only that NH_3 is polar and CH_4 is nonpolar (with no more discussion).

(b) C_2H_6 and C_6H_{14} both have London dispersion forces. The forces in C_6H_{14} are stronger because the molecule is larger and more polarizable. ***2 points***

- Credit is earned for other accurate explanations of London dispersion forces.
- No credit is earned for saying only that C_6H_{14} is heavier or has more mass.

(c) Si is a network covalent solid (***or*** a macromolecule) with strong covalent bonds between atoms. Cl_2 has discrete molecules with weak London dispersion forces between the molecules. Therefore, more energy is required to break the stronger bonds of Si than the weak intermolecular forces of Cl_2. ***2 points***

- No credit is earned for saying only that Si forms a lattice.

(d) MgO and NaF are both ionic solids (***or*** ions are listed to indicate this). The +2 and −2 charges in MgO result in a greater attraction between ions than the +1 and −1 charges in NaF (***or*** according to Coulomb's Law, the attraction between +2 ions and −2 ions is greater than that between +1 ions and −1 ions, ***or*** student shows calculations using Coulomb's Law). ***2 points***

- Credit is earned also for stating that the lattice energy of MgO is greater than the lattice energy of NaF.
- No credit is earned for only a discussion of electronegativity.
- Since the sizes are about the same, no credit is earned for only a size argument.