Note: This document is not a complete practice exam. Rather, it is a compilation of questions from the 2013 AP Chemistry International Exam that support the learning objectives of the redesigned AP course. *Questions that do not support this course have been removed.* This publication may be used to help students prepare for the 2014 AP Chemistry exam and future exams. Following the last page of the exam, there is an answer key as well as the learning objectives which are supported by each of the questions herein.

AP Chemistry:

Sample items from the 2013 administration

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AP EXAM LABEL

TEST BOOK SERIAL NUMBER

CollegeBoard

AP® Chemistry Exam

Monday morning, May 6, 2013

SECTION I: Multiple Choice

2013

I affirm that:

- This exam is being administered on **Monday morning**, **May 6**, **2013**, and will begin between the hours of 8 a.m. and 9 a.m.* If this exam is being offered to me at any other time or any other date, I will refuse to take the exam and will contact the Office of Testing Integrity.
- I will not take this exam booklet from the room or disclose any of the multiple-choice questions to anyone, including my AP teacher.

I understand and accept that my exam score may be canceled if I do not meet these conditions and sign below.

* The administration of this exam in Alaska must begin between 7 a.m. and 8 a.m.

Signature ________________________ Date __________

Print your full legal name here:

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(First) (M.I.) (Last)

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M25IXX1

769272

Form I

Form Code 4JBP4-S

25

AP®

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DO NOT seal answer sheet inside

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AP® Chemistry Exam

SECTION I: Multiple Choice

2013

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
75
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
None allowed

Instructions

Section I of this exam contains 75 multiple-choice questions. Fill in only the circles for numbers 1 through 75 of the answer sheet.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

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Form I
Form Code 4JBP4-S
25

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DO NOT seal answer sheet inside

MATERIAL IN THE FOLLOWING TABLE MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.91	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.02	89 **†Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

*Lanthanide Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
†Actinide Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

GO ON TO THE NEXT PAGE.

CHEMISTRY

Section I

Time—1 hour and 30 minutes

NO CALCULATOR MAY BE USED WITH SECTION I.

Note: For all questions, assume that the temperature is 298 K, the pressure is 1.00 atmosphere, and solutions are aqueous unless otherwise specified.

Throughout the test the following symbols have the definitions specified unless otherwise noted.

T = temperature
P = pressure
V = volume
S = entropy
H = enthalpy
G = Gibbs free energy
R = molar gas constant
n = number of moles
M = molar
m = molal

L, mL = liter(s), milliliter(s)
g = gram(s)
nm = nanometer(s)
atm = atmosphere(s)
mm Hg = millimeters of mercury
J, kJ = joule(s), kilojoule(s)
V = volt(s)
mol = mole(s)

Part A

Directions: Each set of lettered choices below refers to the numbered statements immediately following it. Select the one lettered choice that best fits each statement and then fill in the corresponding circle on the answer sheet. A choice may be used once, more than once, or not at all in each set.

Question 1 refer to the following compounds at 25°C and 1.0 atm.

(A) CO_2
(B) PbO_2
(C) CaO
(D) N_2O_5
(E) Cu_2O

1. Contains an element in a +1 oxidation state

Questions #2 & 3 did not align with the new course and have been removed.

Questions 4-7 refer to the following species.

(A) H_2O
(B) NH_3
(C) BH_3
(D) CH_4
(E) SiH_4

4. Has two lone pairs of electrons

5. Has a central atom with less than an octet of electrons

6. Is predicted to have the largest bond angle

7. Has a trigonal-pyramidal molecular geometry

Questions 8-9 refer to the chemical reactions represented below.

(A) $2\,C_6H_6(l) + 15\,O_2(g) \rightarrow 12\,CO_2(g) + 6\,H_2O(l)$
(B) $C_2H_3O_2^-(aq) + H_3O^+(aq) \rightarrow HC_2H_3O_2(aq) + H_2O(l)$
(C) $4\,H^+(aq) + 4\,Co^{2+}(aq) + O_2(g) + 24\,NH_3(aq) \rightarrow 4\,Co(NH_3)_6{}^{3+}(aq) + 2\,H_2O(l)$
(D) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$
(E) $2\,H_2O_2(l) \rightarrow O_2(g) + 2\,H_2O(l)$

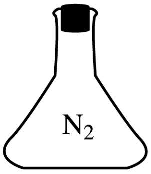
8. The reaction between a Brønsted-Lowry acid and a Brønsted-Lowry base

9. The reaction in which a single species is both oxidized and reduced

Questions #10 - 14 did not align with the new course and have been removed.

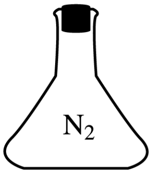
Questions 15-17 refer to the 1 L flasks shown below.

(A)



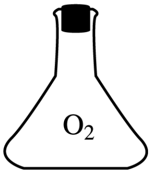
T = 30°C
P = 1 atm

(B)



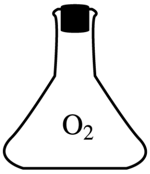
T = 50°C
P = 0.5 atm

(C)



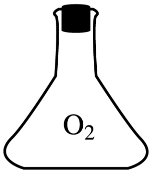
T = 40°C
P = 2 atm

(D)



T = 50°C
P = 1 atm

(E)



T = 40°C
P = 0.5 atm

15. In which flask do the molecules have the greatest average speed?

16. Which flask contains the smallest number of moles of gas?

17. Which flask contains the sample with the greatest density?

GO ON TO THE NEXT PAGE.

Part B

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

18. Which of the following elements has the largest first ionization energy?

(A) Li
(B) Be
(C) B
(D) C
(E) N

19. A 0.20 mol sample of $MgCl_2(s)$ and a 0.10 mol sample of $KCl(s)$ are dissolved in water and diluted to 500 mL. What is the concentration of Cl^- in the solution?

(A) 0.15 *M*
(B) 0.30 *M*
(C) 0.50 *M*
(D) 0.60 *M*
(E) 1.0 *M*

20. Atoms of Mg combine with atoms of F to form a compound. Atoms of which of the following elements combine with atoms of F in the same ratio?

(A) Li
(B) Ba
(C) Al
(D) Cl
(E) Ne

$$C_3H_8(g) + 5\,O_2(g) \rightarrow 3\,CO_2(g) + 4\,H_2O(l)$$

21. In the reaction represented above, what is the total number of moles of reactants consumed when 1.00 mole of $CO_2(g)$ is produced?

(A) 0.33 mol
(B) 1.33 mol
(C) 1.50 mol
(D) 2.00 mol
(E) 6.00 mol

22. How many protons, neutrons, and electrons are in an ${}^{56}_{26}\mathrm{Fe}$ atom?

	Protons	Neutrons	Electrons
(A)	26	30	26
(B)	26	56	26
(C)	30	26	30
(D)	56	26	26
(E)	56	82	56

23. Which of the following is the electron configuration of an excited atom that is likely to emit a quantum of energy?

(A) $1s^2\,2s^22p^6\,3s^23p^1$
(B) $1s^2\,2s^22p^6\,3s^23p^5$
(C) $1s^2\,2s^22p^6\,3s^2$
(D) $1s^2\,2s^22p^6\,3s^1$
(E) $1s^2\,2s^22p^6\,3s^13p^1$

24. Which of the following molecules contains polar covalent bonds but is a nonpolar molecule?

(A) CH_3Cl
(B) CH_2Cl_2
(C) NH_3
(D) CCl_4
(E) N_2

$$H_2 + F_2 \rightarrow 2\,HF$$

25. In the reaction represented above, what mass of HF is produced by the reaction of 3.0×10^{23} molecules of H_2 with excess F_2 ? (Assume the reaction goes to completion.)

(A) 1.0 g
(B) 4.0 g
(C) 10. g
(D) 20. g
(E) 40. g

26. For which of the following reaction mixtures at equilibrium would reducing the volume of the container at constant temperature cause the equilibrium to shift toward the products?

(A) $SrCO_3(s) \rightleftarrows SrO(s) + CO_2(g)$

(B) $C(s) + CO_2(g) \rightleftarrows 2\,CO(g)$

(C) $CO(g) + H_2O(g) \rightleftarrows CO_2(g) + H_2(g)$

(D) $PCl_5(g) \rightleftarrows PCl_3(g) + Cl_2(g)$

(E) $2\,NO_2(g) \rightleftarrows N_2O_4(g)$

Question #27 did not align with the new course and has been removed.

28. A 2 L sample of $N_2(g)$ and a 1 L sample of $Ar(g)$, each originally at 1 atm and 0°C, are combined in a 1 L tank. If the temperature is held constant, what is the total pressure of the gases in the tank?

(A) 1 atm
(B) 2 atm
(C) 3 atm
(D) 4 atm
(E) 5 atm

29. Which of the following processes involves the greatest increase in entropy?

(A) $SO_3(g) + H_2(g) \rightarrow SO_2(g) + H_2O(g)$

(B) $N_2(g) + 3\,H_2(g) \rightarrow 2\,NH_3(g)$

(C) $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

(D) $C_2H_2(g) + 2\,H_2(g) \rightarrow C_2H_6(g)$

(E) $MgSO_3(s) \rightarrow MgO(s) + SO_2(g)$

$$N_2O_5(g) \rightleftarrows 2\,NO_2(g) + \frac{1}{2}O_2(g)$$

30. The equilibrium constant for the gas phase reaction above is 95 at 25°C. What is the value of the equilibrium constant for the following reaction at 25°C?

$$O_2(g) + 4\,NO_2(g) \rightleftarrows 2\,N_2O_5(g)$$

(A) $(95)^2$

(B) 95

(C) $(95)^{\frac{1}{2}}$

(D) $\frac{1}{95}$

(E) $\frac{1}{(95)^2}$

Question #31 doesn not align with the new course and has been removed.

$$C_2H_4(g) + H_2(g) \xrightarrow{\text{platinum}} C_2H_6(g)$$

32. $C_2H_4(g)$ is reduced by $H_2(g)$ in the presence of a solid platinum catalyst, as represented by the equation above. Factors that could affect the rate of the reaction include which of the following?

I. Changes in the partial pressure of $H_2(g)$
II. Changes in the particle size of the platinum catalyst
III. Changes in the temperature of the reaction system

(A) III only
(B) I and II only
(C) I and III only
(D) II and III only
(E) I, II, and III

33. For an experiment, a student needs 100.0 mL of 0.4220 M NaCl. If the student starts with NaCl(s) and distilled water, which of the following pieces of laboratory glassware should the student use to prepare the solution with the greatest accuracy?

(A) 25 mL volumetric pipet
(B) 100 mL Erlenmeyer flask
(C) 100 mL graduated cylinder
(D) 100 mL volumetric flask
(E) 1 L beaker

Questions #34-36 did not align with the new course and have been removed.

$$2\ \mathrm{NH_3}(g) \rightarrow 3\ \mathrm{H_2}(g) + \mathrm{N_2}(g) \quad \Delta H^\circ_{298} = 92\ \mathrm{kJ/mol}_{rxn}$$

37. According to the information above, what is the standard enthalpy of formation, ΔH°_f, for $NH_3(g)$ at 298 K ?

(A) −92 kJ/mol
(B) −46 kJ/mol
(C) 46 kJ/mol
(D) 92 kJ/mol
(E) 184 kJ/mol

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38. The percentage of silver in a solid sample is determined gravimetrically by converting the silver to $Ag^+(aq)$ and precipitating it as silver chloride. Failure to do which of the following could cause errors in the analysis?

I. Account for the mass of the weighing paper when determining the mass of the sample
II. Measure the temperature during the precipitation reaction
III. Wash the precipitate
IV. Heat the AgCl precipitate to constant mass

(A) I only
(B) I and II
(C) I and IV
(D) II and III
(E) I, III, and IV

Question #39 did not align with the new course and has been removed.

$$HSO_4^-(aq) + CO_3^{2-}(aq) \rightleftarrows SO_4^{2-}(aq) + HCO_3^-(aq)$$

40. The reaction represented above is observed to proceed spontaneously to the right in aqueous solution. In this system the strongest base is

(A) $SO_4^{2-}(aq)$
(B) $CO_3^{2-}(aq)$
(C) $H_2O(l)$
(D) $HCO_3^-(aq)$
(E) $HSO_4^-(aq)$

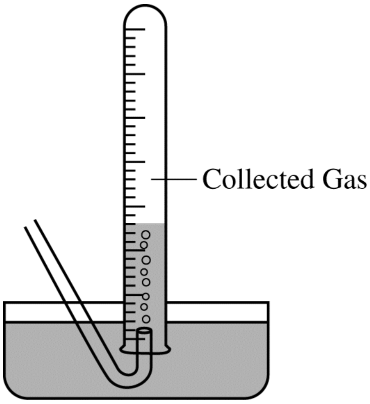
$$\ldots LiHCO_3(aq) + \ldots H_2SO_4(aq) \rightarrow \ldots Li_2SO_4(aq) + \ldots H_2O(l) + \ldots CO_2(g)$$

41. When the equation above is balanced and the coefficients are reduced to lowest whole-number terms, what is the coefficient of $H_2O(l)$?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5

42. Which of the following lists the substances F_2, HCl, and HF in order of increasing boiling point?

(A) $HF < HCl < F_2$
(B) $HF < F_2 < HCl$
(C) $HCl < F_2 < HF$
(D) $HCl < HF < F_2$
(E) $F_2 < HCl < HF$



43. Gases generated in a chemical reaction are sometimes collected by the displacement of water, as shown above. Which of the following gases can be quantitatively collected by this method?

(A) H_2
(B) CO_2
(C) HCl
(D) SO_2
(E) NH_3

44. When a 3.22 g sample of an unknown hydrate of sodium sulfate, $Na_2SO_4 \cdot x\, H_2O(s)$, is heated, H_2O (molar mass 18 g) is driven off. The mass of the anhydrous $Na_2SO_4(s)$ (molar mass 142 g) that remains is 1.42 g. The value of x in the hydrate is

(A) 0.013
(B) 1.8
(C) 6.0
(D) 10.
(E) 20.

45. A 0.10 *M* solution of a weak monoprotic acid has a pH equal to 4.0. The ionization constant, K_a, of the acid is

(A) 1×10^{-3}
(B) 1×10^{-4}
(C) 1×10^{-7}
(D) 1×10^{-8}
(E) 1×10^{-9}

46. In an insulated cup of negligible heat capacity, 50. g of water at 40.°C is mixed with 30. g of water at 20.°C. The final temperature of the mixture is closest to

(A) 22°C
(B) 27°C
(C) 30.°C
(D) 33°C
(E) 38°C

47. Which of the following is an isomer of CH_3OCH_3 ?

(A) CH_3CH_3
(B) CH_3COOH
(C) CH_3CH_2OH
(D) $CH_3CH_2CH_3$
(E) $CH_3CH_2OCH_2CH_3$

48. Potassium hydrogen phthalate, KHP, is used as a primary standard for determining the concentration of a solution of NaOH by titration. If the KHP has not been dried before weighing, the calculated molarity of the NaOH would be

(A) higher than the actual value, since water is included in the apparent mass of KHP
(B) higher than the actual value, since the presence of water requires a larger volume of titrant
(C) lower than the actual value, since NaOH absorbs water
(D) unaffected, since KHP is a strong acid
(E) unaffected, since water is routinely added before the titration

49. Which of the following substances has the greatest solubility in $C_5H_{12}(l)$ at 1 atm?

(A) $SiO_2(s)$
(B) $NaCl(s)$
(C) $H_2O(l)$
(D) $CCl_4(l)$
(E) $NH_3(g)$

Question #50 did not align with the new course and has been removed.

GO ON TO THE NEXT PAGE.

Experiment	Initial [X] (mol L^{-1})	Initial [Y] (mol L^{-1})	Initial Rate of Formation of Z (mol L^{-1} s^{-1})
1	0.10	0.30	4.0×10^{-4}
2	0.20	0.60	1.6×10^{-3}
3	0.20	0.30	4.0×10^{-4}

51. The data in the table above were obtained for the reaction $X + Y \rightarrow Z$. Which of the following is the rate law for the reaction?

(A) Rate $= k[X]^2$
(B) Rate $= k[Y]^2$
(C) Rate $= k[X][Y]$
(D) Rate $= k[X]^2[Y]$
(E) Rate $= k[X][Y]^2$

$$2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(g)$$

52. For the reaction represented above at 25°C, what are the signs of $\Delta H°$, $\Delta S°$, and $\Delta G°$?

	$\Delta H°$	$\Delta S°$	$\Delta G°$
(A)	+	+	+
(B)	+	+	−
(C)	+	−	−
(D)	−	−	−
(E)	−	−	+

53. What is the empirical formula of an oxide of chromium that is 48 percent oxygen by mass?

(A) CrO
(B) CrO_2
(C) CrO_3
(D) Cr_2O
(E) Cr_2O_3

54. High solubility of an ionic solid in water is favored by which of the following conditions?

I. The existence of strong ionic attractions in the crystal lattice
II. The formation of strong ion-dipole attractions
III. An increase in entropy upon dissolving

(A) I only
(B) I and II only
(C) I and III only
(D) II and III only
(E) I, II, and III

55. Which of the following statements is true for the equilibrium vapor pressure of a liquid in a closed system?

(A) It remains constant when the temperature increases.
(B) It decreases to half its original value if the volume of the gas phase is doubled.
(C) It increases to twice its original value if the volume of the liquid phase is doubled.
(D) It decreases to half its original value if the surface area of the liquid is reduced by one-half.
(E) It is independent of the volume of the vapor phase.

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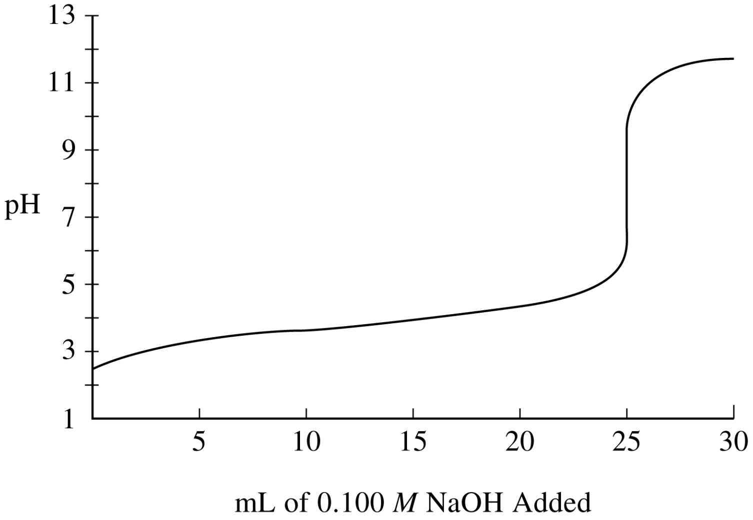


56. An unknown acid is dissolved in 25 mL of water and titrated with 0.100 M NaOH. The results are shown in the titration curve above. Which of the following could be the unknown acid?

(A) Fluoroacetic acid, $pK_a = 2.6$
(B) Glycolic acid, $pK_a = 3.8$
(C) Propanoic acid, $pK_a = 4.9$
(D) Hypochlorous acid, $pK_a = 7.5$
(E) Boric acid, $pK_a = 9.3$

57. Which of the following lists Mg, P, and Cl in order of increasing atomic radius?

(A) Cl < P < Mg
(B) Cl < Mg < P
(C) Mg < P < Cl
(D) Mg < Cl < P
(E) P < Cl < Mg

Question #58 did not align with the new course and has been removed.

$Al^{3+}(aq) + 3\,e^- \rightarrow Al(s) \qquad E° = -1.66\text{ V}$

$Ag^{+}(aq) + e^- \rightarrow Ag(s) \qquad E° = +0.80\text{ V}$

59. According to the standard reduction potentials given above, what is the standard cell potential for the reaction represented below?

$$3\,Ag^{+}(aq) + Al(s) \rightarrow 3\,Ag(s) + Al^{3+}(aq)$$

(A) −1.74 V
(B) −0.86 V
(C) +1.74 V
(D) +2.46 V
(E) +4.06 V

$$X(g) + Y(g) \rightleftarrows 2\,Z(g)$$

60. When 4.00 mol each of $X(g)$ and $Y(g)$ are placed in a 1.00 L vessel and allowed to react at constant temperature according to the equation above, 6.00 mol of $Z(g)$ is produced. What is the value of the equilibrium constant, K_c ?

(A) 3
(B) 6
(C) 8
(D) 16
(E) 36

61. If the oxygen isotope ^{20}O has a half-life of 15 seconds, what fraction of a sample of pure ^{20}O remains after 1.0 minute?

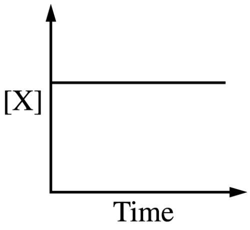
(A) $\frac{1}{2}$
(B) $\frac{1}{4}$
(C) $\frac{7}{30}$
(D) $\frac{1}{8}$
(E) $\frac{1}{16}$

GO ON TO THE NEXT PAGE.

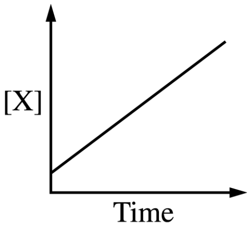
$$X \rightarrow \text{products}$$

62. Pure substance X decomposes according to the equation above. Which of the following graphs indicates that the rate of decomposition is second order in X ?

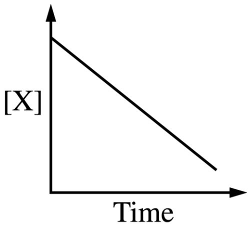
(A)



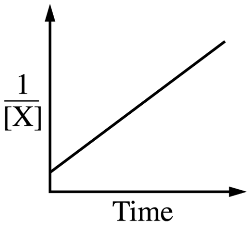
(B)



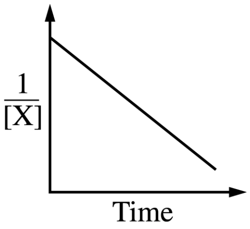
(C)



(D)



(E)



$$2\ \mathrm{MnO_4^-}(aq) + 5\ \mathrm{C_2O_4^{2-}}(aq) + 16\ \mathrm{H^+}(aq) \rightarrow 2\ \mathrm{Mn^{2+}}(aq) + 10\ \mathrm{CO_2}(g) + 8\ \mathrm{H_2O}(l)$$

63. Permanganate and oxalate ions react in an acidified solution according to the balanced equation above. How many moles of $CO_2(g)$ are produced when 20. mL of acidified 0.20 *M* $KMnO_4$ solution is added to 50. mL of 0.10 *M* $Na_2C_2O_4$ solution?

(A) 0.0040 mol
(B) 0.0050 mol
(C) 0.0090 mol
(D) 0.010 mol
(E) 0.020 mol

Question #64 did not align with the new course and has been removed.

$NaOH(aq) + HCl(aq) \rightarrow H_2O(l) + NaCl(aq)$

65. A student is trying to determine the heat of reaction for the acid-base neutralization reaction represented above. The student uses 0.50 *M* NaOH and 0.50 *M* HCl solutions. Which of the following situations, by itself, would most likely result in the LEAST error in the calculated value of the heat of reaction?

(A) The thermometer was incorrectly calibrated and read 0.5 Celsius degree too high during the procedure.
(B) The volume of the acid solution added to the calorimeter was actually 1.0 mL less than what was recorded.
(C) The calorimeter was poorly insulated, and some heat escaped to the atmosphere during the procedure.
(D) The actual molarity of the base solution was 0.53 *M* but was recorded as 0.50 *M*.
(E) The final temperature of the mixture was taken before the contents of the calorimeter had reached thermal equilibrium.

66. A molecular solid coexists with its liquid phase at its melting point. The solid-liquid mixture is heated, but the temperature does not change while the solid is melting. The best explanation for this phenomenon is that the heat absorbed by the mixture

(A) is lost to the surroundings very quickly
(B) is used in overcoming the intermolecular attractions in the solid
(C) is used in breaking the bonds within the molecules of the solid
(D) causes the nonbonding electrons in the molecules to move to lower energy levels
(E) causes evaporation of the liquid, which has a cooling effect

67. The role of a catalyst in a chemical reaction is to

(A) decrease the amount of reactants that must be used
(B) lower the activation energy for the reaction
(C) supply the activation energy required for the reaction to proceed
(D) increase the amounts of products formed at equilibrium
(E) increase the entropy change for the reaction

68. If 50. mL of 1.0 *M* NaOH is diluted with distilled water to a volume of 2.0 L, the concentration of the resulting solution is

(A) 0.025 *M*
(B) 0.050 *M*
(C) 0.10 *M*
(D) 0.50 *M*
(E) 1.0 *M*

69. Which of the following is NOT an accepted name for the formula given?

(A) CH_3OH . . methanol
(B) CuO . . copper(I) oxide
(C) $FeCl_3$ . . iron(III) chloride
(D) H_2SO_4 . . sulfuric acid
(E) $SrCO_3$ . . strontium carbonate

Question #70 did not align with the new course and has been removed.

71. Which of the following molecules contains exactly three sigma (σ) bonds and two pi (π) bonds?

(A) C_2H_2
(B) CO_2
(C) HCN
(D) SO_3
(E) N_2

Question #72 did not align with the new course and has been removed.

73. Resonance is most commonly used to describe the bonding in molecules of which of the following?

(A) CO_2
(B) O_3
(C) H_2O
(D) CH_4
(E) SF_6

74. A student prepares a solution by dissolving 60.00 g of glucose (molar mass 180.2 g mol^{-1}) in enough distilled water to make 250.0 mL of solution. The molarity of the solution should be reported as

(A) 12.01 *M*
(B) 12.0 *M*
(C) 1.332 *M*
(D) 1.33 *M*
(E) 1.3 *M*

75. Which of the following substances is a strong electrolyte when dissolved in water?

(A) Sucrose
(B) Ethanol
(C) Sodium nitrate
(D) Acetic acid
(E) Ammonia

GO ON TO THE NEXT PAGE.

END OF SECTION I

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON THIS SECTION.

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

NO TEST MATERIAL ON THIS PAGE

NO TEST MATERIAL ON THIS PAGE

PLACE SEAL HERE

AP® Chemistry Exam

SECTION I: Multiple Choice

2013

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
75
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
None allowed

Instructions

Section I of this exam contains 75 multiple-choice questions. Fill in only the circles for numbers 1 through 75 of the answer sheet.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a	Ⓐ ● Ⓒ Ⓓ Ⓔ
(A) state	
(B) city	
(C) country	
(D) continent	
(E) village	

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

PLACE SEAL HERE

Form I
Form Code 4JBP4-S
25

PLACE SEAL HERE
DO NOT seal answer sheet inside

TEST BOOK SERIAL NUMBER

CollegeBoard

AP® Chemistry Exam
Monday morning, May 6, 2013

SECTION II: Free Response

2013

I affirm that:

- This exam is being administered on **Monday morning**, **May 6**, **2013**.
- I did not have advance knowledge of the free-response questions, nor did I open the Section II booklet before being instructed to do so by the proctor.
- I will not take this exam booklet from the room, and will only discuss the free-response questions if the specific questions in the exam are released on the College Board website two days after the exam administration. If the questions in this exam are not released, I will not discuss them with anyone.
- I understand that if I do not place my AP number label below, it may be impossible to identify this booklet as my own, which could delay or jeopardize my AP score.

Place AP Number Label Here

Furthermore, **I understand and accept that my exam score may be canceled if I do not meet these conditions and initial here**.

My Initials ☐☐☐ ____________
First M.I. Last Date

T25I

769273

Form I
Form Code 4GBP2-S2

AP

INFORMATION IN THE TABLE BELOW AND IN THE TABLES ON PAGES 3-5 MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.91	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.02	89 **†Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

*Lanthanide Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
†Actinide Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

Half-reaction			$E°$(V)
$F_2(g) + 2e^-$	→	$2F^-$	2.87
$Co^{3+} + e^-$	→	Co^{2+}	1.82
$Au^{3+} + 3e^-$	→	$Au(s)$	1.50
$Cl_2(g) + 2e^-$	→	$2Cl^-$	1.36
$O_2(g) + 4H^+ + 4e^-$	→	$2H_2O(l)$	1.23
$Br_2(l) + 2e^-$	→	$2Br^-$	1.07
$2Hg^{2+} + 2e^-$	→	$Hg_2^{\;2+}$	0.92
$Hg^{2+} + 2e^-$	→	$Hg(l)$	0.85
$Ag^+ + e^-$	→	$Ag(s)$	0.80
$Hg_2^{\;2+} + 2e^-$	→	$2Hg(l)$	0.79
$Fe^{3+} + e^-$	→	Fe^{2+}	0.77
$I_2(s) + 2e^-$	→	$2I^-$	0.53
$Cu^+ + e^-$	→	$Cu(s)$	0.52
$Cu^{2+} + 2e^-$	→	$Cu(s)$	0.34
$Cu^{2+} + e^-$	→	Cu^+	0.15
$Sn^{4+} + 2e^-$	→	Sn^{2+}	0.15
$S(s) + 2H^+ + 2e^-$	→	$H_2S(g)$	0.14
$2H^+ + 2e^-$	→	$H_2(g)$	0.00
$Pb^{2+} + 2e^-$	→	$Pb(s)$	– 0.13
$Sn^{2+} + 2e^-$	→	$Sn(s)$	– 0.14
$Ni^{2+} + 2e^-$	→	$Ni(s)$	– 0.25
$Co^{2+} + 2e^-$	→	$Co(s)$	– 0.28
$Cd^{2+} + 2e^-$	→	$Cd(s)$	– 0.40
$Cr^{3+} + e^-$	→	Cr^{2+}	– 0.41
$Fe^{2+} + 2e^-$	→	$Fe(s)$	– 0.44
$Cr^{3+} + 3e^-$	→	$Cr(s)$	– 0.74
$Zn^{2+} + 2e^-$	→	$Zn(s)$	– 0.76
$2H_2O(l) + 2e^-$	→	$H_2(g) + 2OH^-$	– 0.83
$Mn^{2+} + 2e^-$	→	$Mn(s)$	– 1.18
$Al^{3+} + 3e^-$	→	$Al(s)$	– 1.66
$Be^{2+} + 2e^-$	→	$Be(s)$	– 1.70
$Mg^{2+} + 2e^-$	→	$Mg(s)$	– 2.37
$Na^+ + e^-$	→	$Na(s)$	– 2.71
$Ca^{2+} + 2e^-$	→	$Ca(s)$	– 2.87
$Sr^{2+} + 2e^-$	→	$Sr(s)$	– 2.89
$Ba^{2+} + 2e^-$	→	$Ba(s)$	– 2.90
$Rb^+ + e^-$	→	$Rb(s)$	– 2.92
$K^+ + e^-$	→	$K(s)$	– 2.92
$Cs^+ + e^-$	→	$Cs(s)$	– 2.92
$Li^+ + e^-$	→	$Li(s)$	– 3.05

ATOMIC STRUCTURE

$$E = h\nu \qquad c = \lambda\nu$$

$$\lambda = \frac{h}{m\upsilon} \qquad p = m\upsilon$$

$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

EQUILIBRIUM

$$K_a = \frac{[\mathrm{H^+}][\mathrm{A^-}]}{[\mathrm{HA}]}$$

$$K_b = \frac{[\mathrm{OH^-}][\mathrm{HB^+}]}{[\mathrm{B}]}$$

$$\begin{aligned} K_w &= [\mathrm{OH^-}][\mathrm{H^+}] = 1.0 \times 10^{-14} \text{ @ } 25^\circ\mathrm{C} \\ &= K_a \times K_b \end{aligned}$$

$$\mathrm{pH} = -\log[\mathrm{H^+}],\ \mathrm{pOH} = -\log[\mathrm{OH^-}]$$

$$14 = \mathrm{pH} + \mathrm{pOH}$$

$$\mathrm{pH} = \mathrm{p}K_a + \log\frac{[\mathrm{A^-}]}{[\mathrm{HA}]}$$

$$\mathrm{pOH} = \mathrm{p}K_b + \log\frac{[\mathrm{HB^+}]}{[\mathrm{B}]}$$

$$\mathrm{p}K_a = -\log K_a,\ \mathrm{p}K_b = -\log K_b$$

$$K_p = K_c(RT)^{\Delta n},$$

where Δn = moles product gas − moles reactant gas

THERMOCHEMISTRY/KINETICS

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\begin{aligned} \Delta G^\circ &= \Delta H^\circ - T\Delta S^\circ \\ &= -RT\ln K = -2.303\,RT\log K \\ &= -n\mathcal{F}E^\circ \end{aligned}$$

$$\Delta G = \Delta G^\circ + RT\ln Q = \Delta G^\circ + 2.303\,RT\log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

$$\ln[\mathrm{A}]_t - \ln[\mathrm{A}]_0 = -kt$$

$$\frac{1}{[\mathrm{A}]_t} - \frac{1}{[\mathrm{A}]_0} = kt$$

$$\ln k = \frac{-E_a}{R}\left(\frac{1}{T}\right) + \ln A$$

E = energy
υ = velocity
ν = frequency
n = principal quantum number
λ = wavelength
m = mass
p = momentum

Speed of light, $c = 3.0 \times 10^8$ m s^{-1}

Planck's constant, $h = 6.63 \times 10^{-34}$ J s

Boltzmann's constant, $k = 1.38 \times 10^{-23}$ J K^{-1}

Avogadro's number $= 6.022 \times 10^{23}$ mol^{-1}

Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

1 electron volt per atom = 96.5 kJ mol^{-1}

Equilibrium Constants

K_a (weak acid)
K_b (weak base)
K_w (water)
K_p (gas pressure)
K_c (molar concentrations)

S° = standard entropy
H° = standard enthalpy
G° = standard free energy
E° = standard reduction potential
T = temperature
n = moles
m = mass
q = heat
c = specific heat capacity
C_p = molar heat capacity at constant pressure
E_a = activation energy
k = rate constant
A = frequency factor

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

Gas constant, R = 8.31 J mol^{-1} K^{-1}
= 0.0821 L atm mol^{-1} K^{-1}
= 62.4 L torr mol^{-1} K^{-1}
= 8.31 volt coulomb mol^{-1} K^{-1}

GO ON TO THE NEXT PAGE.

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$\left(P + \frac{n^2a}{V^2}\right)(V - nb) = nRT$$

$$P_A = P_{total} \times X_A, \text{where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + ...$$

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{K} = {}^\circ\text{C} + 273$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$D = \frac{m}{V}$$

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{\boldsymbol{M}}}$$

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

$$KE \text{ per mole} = \frac{3}{2}RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{\boldsymbol{M}_2}{\boldsymbol{M}_1}}$$

$\text{molarity}, M =$ moles solute per liter solution

$\text{molality} =$ moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

OXIDATION-REDUCTION; ELECTROCHEMISTRY

$$Q = \frac{[\text{C}]^c\,[\text{D}]^d}{[\text{A}]^a\,[\text{B}]^b}, \text{ where } a\,\text{A} + b\,\text{B} \rightarrow c\,\text{C} + d\,\text{D}$$

$$I = \frac{q}{t}$$

$$E_{\text{cell}} = E^\circ_{\text{cell}} - \frac{RT}{n\mathcal{F}}\ln Q = E^\circ_{\text{cell}} - \frac{0.0592}{n}\log Q \quad @\ 25^\circ\text{C}$$

$$\log K = \frac{nE^\circ}{0.0592}$$

P = pressure
V = volume
T = temperature
n = number of moles
D = density
m = mass
v = velocity

u_{rms} = root-mean-square speed
KE = kinetic energy
r = rate of effusion
$\boldsymbol{M}$ = molar mass
π = osmotic pressure
i = van't Hoff factor
K_f = molal freezing-point depression constant
K_b = molal boiling-point elevation constant
A = absorbance
a = molar absorptivity
b = path length
c = concentration
Q = reaction quotient
I = current (amperes)
q = charge (coulombs)
t = time (seconds)
E° = standard reduction potential
K = equilibrium constant

Gas constant, $R = 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$
$= 0.0821\ \text{L atm mol}^{-1}\ \text{K}^{-1}$
$= 62.4\ \text{L torr mol}^{-1}\ \text{K}^{-1}$
$= 8.31\ \text{volt coulomb mol}^{-1}\ \text{K}^{-1}$
Boltzmann's constant, $k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$
K_f for $H_2O = 1.86\ \text{K kg mol}^{-1}$
K_b for $H_2O = 0.512\ \text{K kg mol}^{-1}$
1 atm = 760 mm Hg
= 760 torr
STP = $0.00\,^\circ\text{C}$ and 1.0 atm
Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

GO ON TO THE NEXT PAGE.

CHEMISTRY

Section II

(Total time—95 minutes)

Part A

Time—55 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures. Be sure to write all your answers to the questions on the lined pages following each question in this booklet.

Answer Questions 1, 2, and 3. The Section II score weighting for each question is 20 percent.

$$NH_4Cl(s) \rightleftarrows NH_3(g) + HCl(g)$$

1. When solid ammonium chloride is heated, it decomposes as represented above. The value of K_p for the reaction is 0.0792 at 575 K. A 10.0 g sample of solid ammonium chloride is placed in a rigid, evacuated 3.0 L container that is sealed and heated to 575 K. The system comes to equilibrium with some solid NH_4Cl remaining in the container.

   (a) Write the expression for the equilibrium constant for the reaction in terms of partial pressures (i.e., K_p).

   (b) Calculate the partial pressure of $NH_3(g)$, in atm, at equilibrium at 575 K.

   (c) A small amount of $NH_3(g)$ is injected into the equilibrium mixture in the 3.0 L container at 575 K.

      (i) As the new equilibrium is being established at 575 K, does the amount of $NH_4Cl(s)$ in the container increase, decrease, or remain the same? Justify your answer.

      (ii) After the new equilibrium is established at 575 K, is the value of K_p greater than, less than, or equal to the value before the $NH_3(g)$ was injected into the container? Justify your answer.

   (d) When the temperature of the container is lowered to 500 K, the number of moles of $NH_3(g)$ in the container decreases. On the basis of this observation, is the decomposition of $NH_4Cl(s)$ endothermic or exothermic? Justify your answer.

   In another experiment, 20.00 mL of 0.800 M $NH_4Cl(aq)$ is prepared. The ammonium ion reacts with water according to the equation $NH_4^+(aq) + H_2O(l) \rightleftarrows NH_3(aq) + H_3O^+(aq)$.

   (e) Calculate the value of the equilibrium constant for the reaction of the ammonium ion with water. (At 25°C the value of K_b for NH_3 is 1.8×10^{-5}.)

(f) A solution is prepared by mixing 20.0 mL of 0.800 M $NH_3(aq)$ with 20.0 mL of 0.800 M $NH_4Cl(aq)$. Assume that volumes are additive.

(i) Is the solution acidic, basic, or neutral? Justify your answer.

Question #1-fii did not align with the new course and has been removed.

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

GO ON TO THE NEXT PAGE.

$$XClO_3(s) \rightarrow XCl(s) + \frac{3}{2}O_2(g)$$

2. The equation above represents the decomposition of a compound containing an unknown element, X. A 1.39 g sample of $XClO_3(s)$ was completely decomposed by heating. The gas produced by the reaction was captured over water in a gas-collection tube at 24.0°C. The total volume of gas in the tube was 506 mL, and the total pressure inside the tube was determined to be 739.5 torr. The vapor pressure of water is 22.4 torr at 24.0°C.

   (a) Calculate the partial pressure, in torr, of the $O_2(g)$ that was collected at 24.0°C.

   (b) Calculate the number of moles of $O_2(g)$ collected at 24.0°C.

   (c) Determine the number of moles of $XClO_3(s)$ that decomposed.

   (d) Determine the molar mass of the compound.

   (e) Determine the identity of element X.

   In a different experiment, 0.470 mol of $XClO_3(s)$ decomposed at 1.0 atm in the presence of a catalyst as a total of 21.1 kJ of heat was released. The value of ΔG°_{298} for the reaction is -121.5 kJ/mol$_{rxn}$.

   (f) Calculate the value of ΔH°_{298} for the decomposition reaction.

   (g) Which is larger: the sum of the bond energies of the products or the sum of the bond energies of the reactants? Justify your answer.

   (h) How does the presence of a catalyst affect the value of ΔG°_{298} for the reaction? Justify your answer.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

GO ON TO THE NEXT PAGE.

$$2\ \mathrm{NO}(g) + \mathrm{Br_2}(g) \rightarrow 2\ \mathrm{NOBr}(g)$$

3. $NO(g)$ reacts with $Br_2(g)$, as represented by the equation above. An experiment was performed to study the rate of the reaction at 546 K. Data from three trials are shown in the table below.

Trial	Initial [NO] (M)	Initial [Br_2] (M)	Initial Rate of Consumption of Br_2 ($M\ s^{-1}$)
1	0.10	0.20	12.0
2	0.40	0.20	192.0
3	0.10	0.60	36.0

(a) Using the data in the table, determine the order of the reaction with respect to each of the following reactants. In each case, justify your answer.

(i) Br_2

(ii) NO

(b) Write the rate law for the reaction.

(c) Determine the value of the rate constant, k, for the reaction. Include units with your answer.

Question #3-d did not align with the new course and has been removed.

(e) At a later time during trial 2, the concentration of $Br_2(g)$ is determined to be 0.16 M.

(i) Determine the concentration of $NO(g)$ at that time.

(ii) Calculate the rate of consumption of $Br_2(g)$ at that time.

A proposed two-step mechanism for the reaction is represented below.

Step 1: $NO + Br_2 \rightarrow NOBr_2$ *slow (rate-determining step)*

Step 2: $NO + NOBr_2 \rightarrow 2\ NOBr$ *fast*

(f) Is the proposed mechanism consistent with the rate law determined in part (b) ? Justify your answer.

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

S T O P

If you finish before time is called, you may check your work on this part only.
Do not turn to the other part of the test until you are told to do so.

CHEMISTRY

Part B

Time—40 minutes

NO CALCULATORS MAY BE USED FOR PART B.

Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, write a balanced equation in part (i) and answer the question in part (ii). In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be scored.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:

$Mg + 2 Ag^{+} \longrightarrow Mg^{2+} + 2 Ag$

(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

(a) Magnesium metal is strongly heated in a small porcelain container in the presence of oxygen.

(i) Balanced equation:

(ii) Does the mass of the material in the container increase, decrease, or remain the same as the reaction proceeds? Explain.

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Question #4-b did not align with the new course and has been removed.

(c) A solution of silver(I) nitrate is mixed with a solution of potassium sulfide.

Question #4-ci did not align with the new course and has been removed.

(ii) Identify the spectator ions in the reaction that occurs.

YOU MAY USE THE SPACE BELOW FOR SCRATCH WORK, BUT ONLY EQUATIONS THAT ARE WRITTEN IN THE ANSWER BOXES PROVIDED WILL BE SCORED.

Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be scored on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

5. A student is asked to prepare 100.0 mL of $1.000 \times 10^{-2}\ M$ $Na_2SO_4(aq)$ to use in a precipitation experiment. The student first weighs out 0.1420 g of solid Na_2SO_4.

   (a) The balance used to measure the mass of the $Na_2SO_4(s)$ must have a certain minimum level of precision to ensure that the concentration of the Na_2SO_4 solution can be known to four significant figures. If this minimum level of precision of the balance is expressed as $\pm x$ mg, what is the value of x ?

   (b) Describe how the student can best prepare 100.0 mL of $1.000 \times 10^{-2}\ M$ $Na_2SO_4(aq)$ after the appropriate mass of solid Na_2SO_4 has been measured. Circle each item used from the list below and describe the essential steps in the procedure for preparing the solution.

50 mL buret
50 mL volumetric flask
100 mL beaker
Squeeze bottle
100 mL Erlenmeyer flask
100 mL volumetric flask
100 mL graduated cylinder
10 mL volumetric pipet
Distilled water
Dropper

The student is given 250 mL of a solution containing the following cations: Ba^{2+}, Ca^{2+}, Pb^{2+}, and Sr^{2+}. The concentration of each of these cations in the solution is 1.0 M.

   (c) In the first experiment, the student puts 10 mL of the $Ba^{2+}/Ca^{2+}/Pb^{2+}/Sr^{2+}$ solution in a test tube and then adds $1.000 \times 10^{-2}\ M$ $Na_2SO_4(aq)$ one drop at a time, swirling the contents of the test tube after each drop is added. Based on the information in the table below, which salt will be the first to precipitate in the test tube? Justify your answer.

Salt	$BaSO_4$	$CaSO_4$	$PbSO_4$	$SrSO_4$
K_{sp} at 25°C	1.5×10^{-9}	6.1×10^{-5}	1.3×10^{-8}	3.2×10^{-7}

   (d) In a second experiment, the student electrolyzes the $Ba^{2+}/Ca^{2+}/Pb^{2+}/Sr^{2+}$ solution by putting 100 mL of the solution in a beaker and immersing two platinum electrodes in the solution. The electrodes are connected to a source of DC voltage, as shown in the following diagram. The voltage source has a dial that allows the student to increase the voltage slowly. In doing so, the student observes that one of the metals is deposited (plates out) on one of the electrodes.

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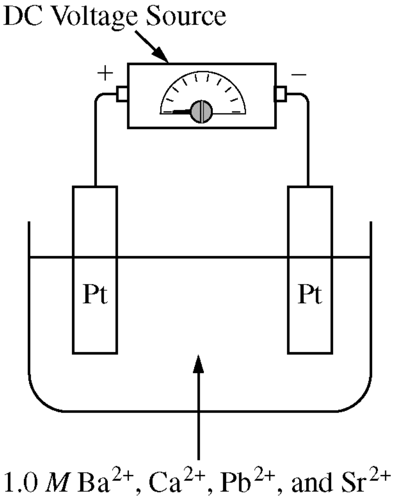

(i) On the diagram, circle the electrode on which the metal plates out. Justify your answer.

(ii) Identify the metal that plates out. Justify your answer.

Question #5-e did not align with the new course and has been removed.

ADDITIONAL PAGE FOR ANSWERING QUESTION 5

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6. Answer the following questions relating to the elements gallium and arsenic.

   (a) Write the ground-state electron configuration for an atom of each of the following.

      (i) Ga

      (ii) As

   (b) Consider the information in the table below.

	First Ionization Energy (kJ mol^{-1})	Second Ionization Energy (kJ mol^{-1})
Gallium	580	1,980
Arsenic	950	1,800

      (i) Explain, in terms of atomic structure, why As has a higher first ionization energy than Ga.

      (ii) Explain, in terms of atomic structure, why Ga has a higher second ionization energy than As.

   (c) Consider the Ga^+ ion.

      (i) Identify an ion of As that is isoelectronic with Ga^+.

      (ii) Which species has a larger radius: Ga^+ or the ion you identified in part (c)(i) ? Explain.

   (d) Arsenic reacts with fluorine to form AsF_5 .

      (i) Draw the complete Lewis electron-dot diagram for the AsF_5 molecule.

      (ii) Are all of the F–As–F bond angles in the AsF_5 molecule the same? Explain.

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

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ADDITIONAL PAGE FOR ANSWERING QUESTION 6

STOP

END OF EXAM

IF YOU FINISH PART B OF SECTION II BEFORE TIME IS CALLED, YOU MAY RETURN TO PART A OF SECTION II IF YOU WISH, BUT YOU MAY NOT USE A CALCULATOR.

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX(ES) ON THE COVER(S).**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

NO TEST MATERIAL ON THIS PAGE

AP® Chemistry Exam

SECTION II: Free Response

2013

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour, 35 minutes
Number of Questions
6
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink

Part A

Number of Questions
3
Time
55 minutes
Electronic Device
Calculator allowed
Percent of Section II Score
Question 1 — 20%
Question 2 — 20%
Question 3 — 20%

Part B

Number of Questions
3
Time
40 minutes
Electronic Device
None allowed
Percent of Section II Score
Question 4 — 10%
Question 5 — 15%
Question 6 — 15%

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Part A and Part B are printed in this booklet. Pages containing a periodic table, reduction potentials, and lists containing equations and constants are also printed in this booklet.

The proctor will announce the times for Part A and Part B; you may not begin working on Part B until the proctor tells you to do so. However, you may proceed freely from one question to the next within each part.

You may use the pages that the questions are printed on to organize your answers or for scratch work, but you must write your answers in the areas designated for each response.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. Manage your time carefully. Do not spend too much time on any one question. If you finish Part B before time is called, you may go back to Part A, but you may NOT use a calculator.

Form I
Form Code 4GBP2-S2

AP® CHEMISTRY
2013 SCORING GUIDELINES

Question 1
(10 points)

$$NH_4Cl(s) \rightleftarrows NH_3(g) + HCl(g)$$

1. When solid ammonium chloride is heated, it decomposes as represented above. The value of K_p for the reaction is 0.0792 at 575 K. A 10.0 g sample of solid ammonium chloride is placed in a rigid, evacuated 3.0 L container that is sealed and heated to 575 K. The system comes to equilibrium with some solid NH_4Cl remaining in the container.

(a) Write the expression for the equilibrium constant for the reaction in terms of partial pressures (i.e., K_p).

$K_p = P_{NH_3}P_{HCl}$	One point is earned for correct equation.

Brackets'[]' earn zero points. Parentheses are acceptable.

(b) Calculate the partial pressure of $NH_3(g)$, in atm, at equilibrium at 575 K.

$0.0792 = P_{NH_3}P_{HCl} = x^2$ $x = 0.281$ atm	One point is earned for correct numerical result.

(c) A small amount of $NH_3(g)$ is injected into the equilibrium mixture in the 3.0 L container at 575 K.

(i) As the new equilibrium is being established at 575 K, does the amount of $NH_4Cl(s)$ in the container increase, decrease, or remain the same? Justify your answer.

Increase. Upon addition of $NH_3(g)$ the reaction will proceed to the left to return to equilibrium. This will result in an increase in $NH_4Cl(s)$.	One point is earned for correct choice with explanation.

Look for 'shifts left', NH_4Cl inc, because equilibrium shifts to reactants.

(ii) After the new equilibrium is established at 575 K, is the value of K_p greater than, less than, or equal to the value before the $NH_3(g)$ was injected into the container? Justify your answer.

The same. The equilibrium constant is unaffected by change in concentration or pressure; only changes in temperature affect K.	One point is earned for correct choice with explanation.

(d) When the temperature of the container is lowered to 500 K, the number of moles of $NH_3(g)$ in the container decreases. On the basis of this observation, is the decomposition of $NH_4Cl(s)$ endothermic or exothermic? Justify your answer.

Endothermic. A decrease in T causes a reaction originally at equilibrium to proceed in the exothermic direction. Since the decrease in T in this case causes the reaction to proceed toward reactants, the forward reaction must be endothermic.	One point is earned for correct choice with explanation.

Question 1 (continued)

In another experiment, 20.00 mL of 0.800 M $NH_4Cl(aq)$ is prepared. The ammonium ion reacts with water according to the equation $NH_4^+(aq) + H_2O(l) \rightleftarrows NH_3(aq) + H_3O^+(aq)$.

(e) Calculate the value of the equilibrium constant for the reaction of the ammonium ion with water. (At 25°C the value of K_b for NH_3 is 1.8×10^{-5}.)

$K_a = K_w/K_b = (1.00 \times 10^{-14})/(1.8 \times 10^{-5}) = 5.6 \times 10^{-10}$	One point is earned for correct numerical result.

(f) A solution is prepared by mixing 20.0 mL of 0.800 M $NH_3(aq)$ with 20.0 mL of 0.800 M $NH_4Cl(aq)$. Assume that volumes are additive.

(i) Is the solution acidic, basic, or neutral? Justify your answer.

Basic: $K_a = \frac{[NH_3][H_3O^+]}{[NH_4^+]}$; in this case $[NH_3]=[NH_4^+]$, so $K_a = [H_3O^+]$. Thus pH = pK_a. pK_a = -logK_a = -(-9.26) = 9.26. or K_b for the weak base is larger than K_a for the weak acid, so the solution must be basic.	One point is earned for indicating that pH = pK_a. One point is earned for correct choice based on correctly calculating or noting the value of pH. NOTE: Be consistent if K_a calculated in part (e) is larger than K_b.

(ii) Calculate the pH of the solution that would result from adding 0.0200 mol of HCl to the solution. Assume that the addition of the HCl does not change the volume of the solution.

$NH_3(aq) + H^+(aq) \rightleftarrows NH_4^+(aq)$ I 0.0160 0.0200 0.0160 C -0.0160 -0.0160 +0.0160 E 0 0.0040 0.0320 $[H_3O^+] = (0.0040)/(0.040) = 0.10M$; pH = 1.00	One point is earned for correct calculation of moles or concentration of reactants *prior* to reaction. One point is earned for correct numerical value of pH.

Question 2
(10 points)

$$XClO_3(s) \rightarrow XCl(s) + \frac{3}{2}O_2(g)$$

2. The equation above represents the decomposition of a compound containing an unknown element, X. A 1.39 g sample of $XClO_3(s)$ was completely decomposed by heating. The gas produced by the reaction was captured over water in a gas-collection tube at 24.0°C. The total volume of gas in the tube was 506 mL, and the total pressure inside the tube was determined to be 739.5 torr. The vapor pressure of water is 22.4 torr at 24.0°C.

(a) Calculate the partial pressure, in torr, of the $O_2(g)$ that was collected at 24.0°C.

$P_{O2} = P_{gas} - P_{vp,water} = (739.5\text{-}22.4)\text{ torr} = 717.1\text{torr}$	One point is earned for correct numerical result. Look for the answer to the tenth of a decimal place. Deduct significant figure point if absent.

(b) Calculate the number of moles of $O_2(g)$ collected at 24.0°C.

$n = \frac{(717.1/760)(0.506)}{(0.0821)(297)} = 1.96x10^{\ 2}\text{mol}$	One point is earned for correct setup. One point is earned for correct numerical result.

(c) Determine the number of moles of $XClO_3(s)$ that decomposed.

$1.96x10^{\ 2}\text{mol } O_2 \left(\frac{1\text{ mol } XClO_3}{\frac{3}{2}\text{mol } O_2}\right) = 1.31 \text{ x } 10^{-2}\text{mol } XClO_3$	One point is earned for correct numerical result.

(d) Determine the molar mass of the compound.

$\frac{1.39\text{ g } XClO_3}{1.31x10^{-2}\text{mol}} = 106\text{g/mol}$	One point is earned for correct numerical result.

(e) Determine the identity of element X.

$106\text{ g mol}^{-1} - 35.45\text{ g mol}^{-1} - 3(16.0\text{ g mol}^{-1})$ $= 23.0\text{ g mol}^{-1}$; element = Na	One point for calculation of correct atomic mass. One point for correct selection of element. Because the molar mass is not asked for it is not subject to significant figure rule.

Question 2 (continued)

In a different experiment, 0.470 mol of $XClO_3(s)$ decomposed at 1.0 atm in the presence of a catalyst as a total of 21.1 kJ of heat was released. The value of ΔG°_{298} for the reaction is −121.5 kJ/mol$_{rxn}$.

(f) Calculate the value of ΔH°_{298} for the decomposition reaction.

$\frac{-21.1 \text{ kJ}}{0.470 \text{ mol}} = -\ 44.9 \text{ kJ/mol}_{rxn}$	One point for correct numerical value. The value must have a negative sign.

(g) Which is larger: the sum of the bond energies of the products or the sum of the bond energies of the reactants? Justify your answer.

Sum of the bond energies of products is greater; since the reaction is exothermic, more energy must be released in the formation of product bonds than is required in the breaking of reactant bonds.	One point is earned for correct choice with explanation.

ΔG° cannot be used to explain bond energy.

(h) How does the presence of a catalyst affect the value of ΔG°_{298} for the reaction? Justify your answer.

It has no effect. ΔG° is unaffected by the introduction of a catalyst. A catalyst affects only the rate at which equilibrium is reached, not the position of equilibrium.	One point is earned for correct choice with explanation.

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Question 3
(9 points)

$$2\ NO(g) + Br_2(g) \rightarrow 2\ NOBr(g)$$

3. NO(g) reacts with $Br_2(g)$, as represented by the equation above. An experiment was performed to study the rate of the reaction at 546 K. Data from three trials are shown in the table below.

Trial	Initial [NO] (M)	Initial [Br_2] (M)	Initial Rate of Consumption of Br_2 ($M\ s^{-1}$)
1	0.10	0.20	12.0
2	0.40	0.20	192.0
3	0.10	0.60	36.0

(a) Using the data in the table, determine the order of the reaction with respect to each of the following reactants. In each case, justify your answer.

(i) Br_2

1st order; tripling [Br_2] triples the rate of reaction.	One point is earned for correct order with justification.

(ii) NO

2nd order. Quadrupling [NO] increases the rate by 16x.	One point is earned for correct order with justification.

(b) Write the rate law for the reaction.

Rate = k $[NO]^2[Br_2]$	One point is earned for the correct equation.

(c) Determine the value of the rate constant, k, for the reaction. Include units with your answer.

$12.0\ M\ s^{-1} = k(0.10)^2(0.20)$ $k = 6.0 \times 10^3\ M^{-2}s^{-1}$	One point is earned for setup. One point is earned for correct numerical result with correct units.

Question 3 (continued)

(d) For trial 1, determine the initial rate of formation of NOBr(*g*), in *M* s^{-1}.

Rate of Consumption of $Br_2 = \frac{1}{2}\cdot$rate of formation of NOBr(*g*) $\text{Rate} = -\frac{1}{2}\frac{\Delta[NOBr]}{\Delta t}$ $12\ M\ s^{-1} = \frac{1}{2}\frac{\Delta[NOBr]}{\Delta t}$ $24\ M\ s^{-1} = \frac{\Delta[NOBr]}{\Delta t}$	$\text{Rate} = -\frac{\Delta[Br_2]}{\Delta t} = \frac{1}{2}\frac{\Delta[NOBr]}{\Delta t}$ $12\ M\ s^{-1} = \frac{1}{2}\frac{\Delta[NOBr]}{\Delta t}$ $24\ M\ s^{-1} = \frac{\Delta[NOBr]}{\Delta t}$	One point is earned for correct numerical result.

(e) At a later time during trial 2, the concentration of $Br_2(g)$ is determined to be 0.16 *M*.

(i) Determine the concentration of NO(*g*) at that time.

$[Br_2]_{\text{reacting}} = [Br_2]_{\text{initial}} - [Br_2]_{\text{remaining}}$ $[Br_2]_{\text{reacting}} = 0.20\ M - 0.16\ M = 0.040\ M$ $[NO] = 0.40\ M - 0.04\ M(\frac{2\ \text{mol NO}}{1\ \text{mol}\ Br_2}) = 0.32M$	One point is earned for correct numerical result.

(iii) Calculate the rate of consumption of $Br_2(g)$ at that time.

$r = (6.0 \times 10^3\ M^{-2}s^{-1})(0.32\ M)^2(0.16\ M) = 98M\ s^{-1}$	One point is earned for correct numerical result.

A proposed two-step mechanism for the reaction is represented below.

Step 1: $NO + Br_2 \rightarrow NOBr_2$ slow (rate-determining step)

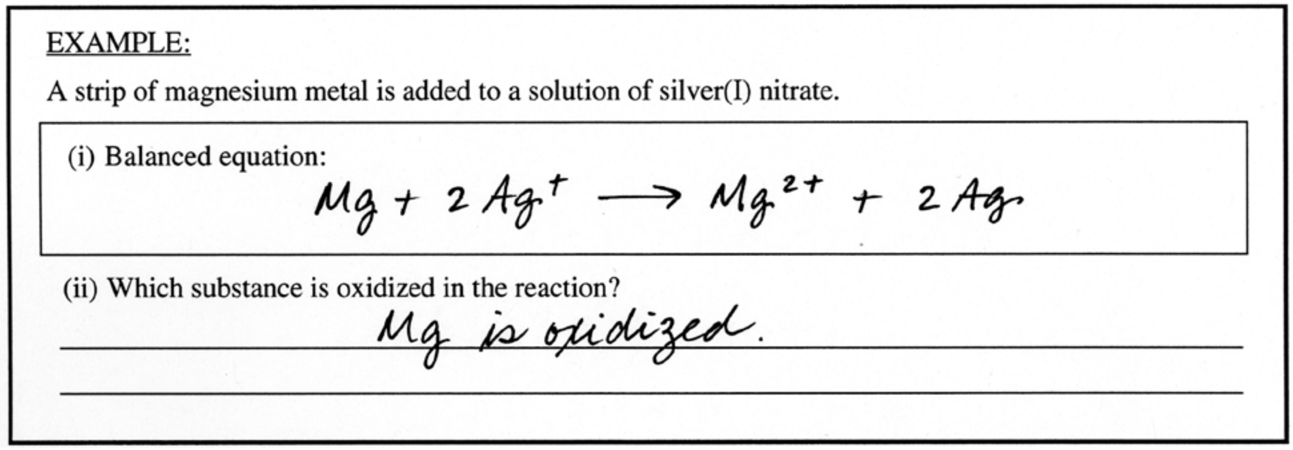
Step 2: $NO + NOBr_2 \rightarrow 2\ NOBr$ fast

(f) Is the proposed mechanism consistent with the rate law determined in part (b) ? Justify your answer.

No. The rate law for the proposed mechanism would be 1st order in NO, but the experimental rate law is 2nd order in NO.	One point is earned for correct response with explanation.

Question 4
(15 points)

4. For each of the following three reactions, write a balanced equation for the reaction in part (i) and answer the question about the reaction in part (ii). In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be scored.



EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:

$Mg + 2\,Ag^{+} \longrightarrow Mg^{2+} + 2\,Ag$

(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

(a) Magnesium metal is strongly heated in a small porcelain container in the presence of oxygen.

(i) Balanced equation:

$2\,Mg(s) + O_2(g) \rightarrow 2\,MgO(s)$	Two points are earned for reactants. One point is earned for product. One point is earned for correct balancing.

(iii) Does the mass of the material in the container increase, decrease, or remain the same as the reaction proceeds? Explain.

The mass increases because the mass of oxygen is added to the mass of magnesium in forming the oxide.	One point is earned for correct answer with explanation.

Question 4 (continued)

(b) In a solution of sodium ethanoate (sodium acetate), the ethanoate ion reacts with water.

(i) Balanced equation:	
$CH_3COO^-(aq) + H_2O(l) \rightarrow CH_3COOH(aq) + OH^-(aq)$	One point is earned for reactants. Two points are earned for products. One point is earned for correct balancing.

(iii) Indicate whether the resulting solution is neutral, acidic, or basic. Explain.

The solution would be basic because OH^- is a product of the reaction.	One point is earned for correct choice with explanation.

For a product that is not H^+ or OH^-, the student must explain that the product produces H^+ or OH^-, to earn the explanation point in ii.

(c) A solution of silver(I) nitrate is mixed with a solution of potassium sulfide.

(i) Balanced equation:	
$2\ Ag^+(aq) + S^{2-}(aq) \rightarrow Ag_2S(s)$	Two points is earned for reactants. One point are earned for the product. One point is earned for balancing.

$AgNO_3 + K_2S \rightarrow Ag_2S(s) + 2KNO_3$ 1 pt R and 1 pt P

(ii) Identify the spectator ions in the reaction that occurs.

The spectator ions are K^+ and NO_3^-.	One point is earned for correct identification of both ions.

One point earned when the spectator ion(s) have the correct formulas and charges. Both ions must be correct for the point.

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Question 5
(8 points)

5. A student is asked to prepare 100.0 mL of 1.000×10^{-2} M $Na_2SO_4(aq)$ to use in a precipitation experiment. The student first weighs out 0.1420 g of solid Na_2SO_4.

(a) The balance used to measure the mass of the $Na_2SO_4(s)$ must have a certain minimum level of precision to ensure that the concentration of the Na_2SO_4 solution can be known to four significant figures. If this minimum level of precision of the balance is expressed as $\pm x$ mg, what is the value of x ?

±0.1 mg	One point is earned for correct answer.

(b) Describe how the student can best prepare 100.0 mL of 1.000×10^{-2} M $Na_2SO_4(aq)$ after the appropriate mass of solid Na_2SO_4 has been measured. Circle each item used from the list below and describe the essential steps in the procedure for preparing the solution.

- 50 mL buret
- 50 mL volumetric flask
- 100 mL beaker
- Squeeze bottle
- 100 mL Erlenmeyer flask
- 100 mL volumetric flask
- 100 mL graduated cylinder
- 10 mL volumetric pipet
- Distilled water
- Dropper

Circle: 100 mL volumetric flask Distilled water Dropper Mass of Na_2SO_4 is transferred to 100 mL volumetric flask. Less than 100 mL of distilled water is added to the flask and the flask is swirled until the salt dissolves. When completely dissolved, distilled water is added until the solution's meniscus is at the calibration mark on the flask's neck, the last few mL's being added with a dropper.	One point is earned for selection of items. One point is earned for essential steps.

Question 5 (continued)

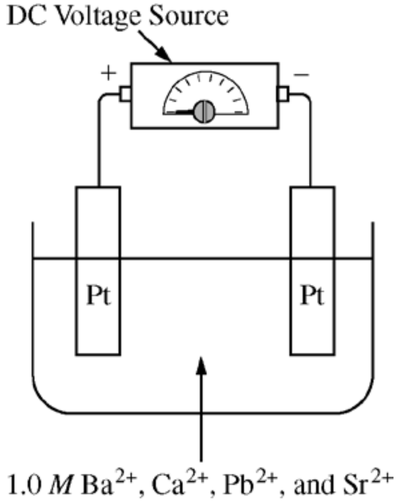
The student is given 250 mL of a solution containing the following cations: Ba^{2+}, Ca^{2+}, Pb^{2+}, and Sr^{2+}. The concentration of each of these cations in the solution is 1.0 *M*.

(c) In the first experiment, the student puts 10 mL of the $Ba^{2+}/Ca^{2+}/Pb^{2+}/Sr^{2+}$ solution in a test tube and then adds 1.000×10^{-2} *M* $Na_2SO_4(aq)$ one drop at a time, swirling the contents of the test tube after each drop is added. Based on the information in the table below, which salt will be the first to precipitate in the test tube? Justify your answer.

Salt	$BaSO_4$	$CaSO_4$	$PbSO_4$	$SrSO_4$
K_{sp} at 25°C	1.5×10^{-9}	6.1×10^{-5}	1.3×10^{-8}	3.2×10^{-7}

$BaSO_4$. The first to precipitate will be the salt, the K_{sp} of which will be the first to be exceeded by the ion product, $[M^{2+}][SO_4^{2-}]$. That salt will be the one with the smallest K_{sp}, thus $BaSO_4$ is chosen.	One point is earned for selection and explanation.

(d) In a second experiment, the student electrolyzes the $Ba^{2+}/Ca^{2+}/Pb^{2+}/Sr^{2+}$ solution by putting 100 mL of the solution in a beaker and immersing two platinum electrodes in the solution. The electrodes are connected to a source of DC voltage, as shown in the following diagram. The voltage source has a dial that allows the student to increase the voltage slowly. In doing so, the student observes that one of the metals is deposited (plates out) on one of the electrodes.



(i) On the diagram, circle the electrode on which the metal plates out. Justify your answer.

Circle electrode on the right. Electrons flow out of the negative pole of the voltage source. These electrons combine with the metal ion at the electrode into which they flow: $M^{2+} + 2e^- \rightarrow M$.	One point is earned for choice and justification.

Cations move towards the negative electrode and are reduced, plated out. Circle the negative electrode and indicate reductions occurs at the cathode and metal cations are reduced.

Question 5 (continued)

(ii) Identify the metal that plates out. Justify your answer.

Pb; it has the most positive reduction potential; therefore its ion is the most easily reduced.	One point is earned for selection. One point is earned for explanation.

(e) After the experiment has been completed, the $Ba^{2+}/Ca^{2+}/Pb^{2+}/Sr^{2+}$ solution must be disposed of. Is pouring the solution down the drain in the laboratory sink followed by rinsing the sink with a large volume of water an appropriate method of disposal? Explain.

No. The solution contains ions that are toxic and/or are not good for the environment, especially lead and barium.	One point is earned for choice and explanation.

Reacts with pipes is not acceptable.

Question 6
(8 points)

6. Answer the following questions relating to the elements gallium and arsenic.

(a) Write the ground-state electron configuration for an atom of each of the following.

(i) Ga

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^1$ or $[Ar]4s^2 3d^{10} 4p^1$	One point is earned for correct configuration.

(ii) As

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$ or $[Ar]4s^2 3d^{10} 4p^3$	One point is earned for correct configuration.

(b) Consider the information in the table below

	First Ionization Energy (kJ mol^{-1})	Second Ionization Energy (kJ mol^{-1})
Gallium	580	1,980
Arsenic	950	1,800

(i) Explain, in terms of atomic structure, why As has a higher first ionization energy than Ga.

The electron ionized from As experiences a higher nuclear charge than the electron ionized from Ga, simply because the As nucleus has two more protons than the Ga nucleus.	One point is earned for the correct explanation.

(ii) Explain, in terms of atomic structure, why Ga has a higher second ionization energy than As.

The second electron removed from Ga comes from the 4s subshell which is lower in energy compared to the second electron removed from As, which comes from the 4p subshell.	One point is earned for the correct explanation.

Question 6 (continued)

(d) Consider the Ga^+ ion.

(i) Identify an ion of As that is isoelectronic with Ga^+.

As^{3+}	One point is earned for correct identification of the ion.

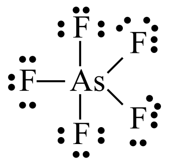
(ii) Which species has a larger radius: Ga^+ or the ion you identified in part (c)(i) ? Explain.

Ga^+ would be larger; the outer electrons in the Ga^+ ion are held less tightly because the Ga nucleus has fewer protons than the As nucleus. The result is a larger ion.	One point is earned for the correct choice with a correct explanation.

Must be consistent with the response in (c)(i).

(d) Arsenic reacts with fluorine to form AsF_5 .

(i) Draw the complete Lewis electron-dot diagram for the AsF_5 molecule.

	One point is earned for the correct Lewis structure.

(ii) Are all of the F–As–F bond angles in the AsF_5 molecule the same? Explain.

No; the structure is trigonal bipyramidal, so the angle between the axial F and the equatorial F is 90° while the angle between the equatorial F's is 120°. The angle between axial F's is 180°	One point is earned for the correct response with explanation.

Consistent with the structure in d(i). For example, trigonal bipyramidal and consists of two different angles, or a difference in angles.

2013 AP Chemistry International Exam Multiple Choice Questions

Question #	Key	Aligned Learning Objective	Secondary Learning Objective
1	E	LO 3.8 The student is able to identify redox reactions and justify the identification in terms of electron transfer. [See SP 6.1]	
4	A	LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]	
5	C	LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]	
6	C	LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]	
7	B	LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]	
8	B	LO 3.7 The student is able to identify compounds as Bronsted-Lowry acids, bases, and/or conjugate acid-base pairs, using proton-transfer reactions to justify the identification. [See SP 6.1]	
9	E	LO 3.8 The student is able to identify redox reactions and justify the identification in terms of electron transfer. [See SP 6.1]	
15	B	LO 2.4 The student is able to use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and nonideal behaviors. [See SP 1.4, 6.4]	
16	B	LO 2.6 The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [See SP 2.2, 2.3]	
17	C	LO 2.6 The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [See SP 2.2, 2.3]	LO 1.4 The student is able to connect the number of particles, moles, mass, and
18	E	LO 1.9 The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model. [See SP 6.4]	
19	E	LO 1.4 The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively.[See SP 7.1]	
20	B	LO 1.10 Students can justify with evidence the arrangement of the periodic table and can apply periodic properties to chemical reactivity. [See SP 6.1]	LO 1.11 The student can analyze data, based on periodicity and the properties of binary compounds, to

21	D	LO 3.3 The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results. [See SP 2.2, 5.1]	
22	A	LO 1.5 The student is able to explain the distribution of electrons in an atom or ion based upon data. [See SP 1.5, 6.2]	
23	E	LO 1.8 The student is able to explain the distribution of electrons using Coulomb's Law to analyze measured energies. [See SP 6.2]	
24	D	LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]	
25	D	LO 3.3 The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results. [See SP 2.2, 5.1]	
26	E	LO 6.8 The student is able to use LeChatelier's principle to predict the direction of the shift resulting from various possible stresses on a system at chemical equilibrium. [See SP 1.4, 6.4]	
28	C	LO 2.6 The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [See SP 2.2, 2.3]	
29	E	LO 5.12 The student is able to use representations and models to predict the sign and relative magnitude of the entropy change associated with chemical or physical processes. [See SP 1.4]	
30	E	LO 6.2 The student can, given a manipulation of a chemical reaction or set of reactions (e.g., reversal of reaction or addition of two reactions), determine the effects of that manipulation on Q or K. [See SP 2.2]	
32	E	LO 4.1 The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction. [See SP 4.2, 5.1]	
33	D	LO 1.19 The student can design, and/or interpret data from, an experiment that uses gravimetric analysis to determine the concentration of an analyte in a solution. [See SP 4.2, 5.1, 6.4]	LO 1.20 The student can design, and/or interpret data from, an experiment that
37	B	LO 5.8 The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds. [See SP 2.3, 7.1, 7.2]	
38	E	LO 1.19 The student can design, and/or interpret data from, an experiment that uses gravimetric analysis to determine the concentration of an analyte in a solution. [See SP 4.2, 5.1, 6.4]	
40	B	LO 6.7 The student is able, for a reversible reaction that has a large or small K, to determine which chemical species will have very large versus very small concentrations at equilibrium. [See SP 2.2, 2.3]	LO 6.17 The student can, given an arbitrary mixture of weak and strong acids and bases (including polyprotic systems), determine
41	B	LO 1.18 The student is able to apply conservation of atoms to the rearrangement of atoms in various processes. [See SP 1.4]	

42	E	LO 2.16 The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces. [See SP 6.2]	
43	A	LO 2.15 The student is able to explain observations regarding the solubility of ionic solids and molecules in water and other solvents on the basis of particle views that include intermolecular interactions and entropic effects. [See SP 1.4, 6.2, connects to 5.E.1]	
44	D	LO 1.2 The student is able to select and apply mathematical routines to mass data to identify or infer the composition of pure substances and/or mixtures. [See SP 2.2]	LO 1.4 The student is able to connect the number of particles, moles, mass, and
45	C	LO 6.16 The student can identify a given solution as being the solution of a monoprotic weak acid or base (including salts in which one ion is a weak acid or base), and calculate the pH and concentration of all species in the solution and/ or infer the relative strengths of the weak acids or bases from given equilibrium concentrations. [See SP 2.2, 6.4]	
46	D	LO 5.5 The student is able to use conservation of energy to relate the magnitudes of the energy changes when two nonreacting substances are mixed or brought into contact with one another. [See SP 2.2, connects to 5.B.1, 5.B.2]	
47	C	LO 1.18 The student is able to apply conservation of atoms to the rearrangement of atoms in various processes. [See SP 1.4]	
48	A	LO 1.20 The student can design, and/or interpret data from, an experiment that uses titration to determine the concentration of an analyte in a solution. [See SP 4.2, 5.1, 6.4]	
49	D	LO 2.15 The student is able to explain observations regarding the solubility of ionic solids and molecules in water and other solvents on the basis of particle views that include intermolecular interactions and entropic effects. [See SP 1.4, 6.2, connects to 5.E.1]	
51	B	LO 4.2 The student is able to analyze concentration vs. time data to determine the rate law for a zeroth-, first-, or second-order reaction. [See SP 5.1,6.4 connects to 4.A.3]	
52	D	LO 5.13 The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both ΔH° and ΔS°, and calculation or estimation of ΔG°when needed. [See SP 2.2, 2.3, 6.4, connects to 5.E.3]	
53	C	LO 1.2 The student is able to select and apply mathematical routines to mass data to identify or infer the composition of pure substances and/or mixtures. [See SP 2.2]	
54	D	LO 2.14 The student is able to apply Coulomb’s Law qualitatively (including using representations) to describe the interactions of ions, and the attractions between ions and solvents to explain the factors that contribute to the solubility of ionic compounds. [See SP 1.4, 6.4]	

55	E	LO 6.3 The student can connect kinetics to equilibrium by using reasoning about equilibrium, such as LeChatelier's principle, to infer the relative rates of the forward and reverse reactions. [See SP 7.2]	
56	B	LO 6.13 The student can interpret titration data for monoprotic or polyprotic acids involving titration of a weak or strong acid by a strong base (or a weak or strong base by a strong acid) to determine the concentration of the titrant and the pKa for a weak acid, or the pKb for a weak base. [See SP 5.1, 6.4, connects to 1.E.2]	
57	A	LO 1.9 The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model. [See SP 6.4]	
59	D	LO 3.12 The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faradays laws. [See SP 2.2, 2.3, 6.4]	
60	E	LO 6.5 The student can, given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, K. [See	
61	E	LO 4.3 The student is able to connect the half-life of a reaction to the rate constant of a first-order reaction, and justify the use of this relation in terms of the reaction being a first-order reaction. [See SP 2.1, 2.2]	
62	D	LO 4.2 The student is able to analyze concentration vs. time data to determine the rate law for a zeroth-, first-, or second-order reaction. [See SP 5.1,6.4 connects to 4.A.3]	
63	D	LO 3.3 The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results. [See SP 2.2, 5.1]	
65	A	LO 5.7 The student is able to design and/or interpret the results of an experiment in which calorimetry is used to determine the change in enthalpy of a chemical process (heating/cooling, phase transition, or chemical reaction) at constant pressure. [See SP 4.2, 5.1, 6.4]	
66	B	LO 5.6 The student is able to use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/ vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to PΔV work. [See SP 2.2, 2.3]	
67	B	LO 4.9 The student is able to explain changes in reaction rates arising from the use of acid-base catalysts, surface catalysts, or enzyme catalysts, including selecting appropriate mechanisms with or without the catalyst present. [See SP 6.2, 7.2]	
68	A	LO 1.4 The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively.[See SP 7.1]	LO 2.9 The student is able to create or interpret
69	B	LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]	

71	A	LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]	
73	B	LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]	
74	C	LO 1.4 The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively.[See SP 7.1]	
75	C	LO 2.8 The student can draw and/or interpret representations of solutions that show the interactions between the solute and solvent. [See SP 1.1, 1.2, 6.4]	

2013 AP Chemistry International Exam Free Response Questions

Question	**Alignment Exceptions**	**Aligned Learning Objectives**
1	except fii	**LO 6.1** The student is able to, given a set of experimental observations regarding physical, chemical, biological, or environmental processes that are reversible, construct an explanation that connects the observations to the reversibility of the underlying chemical reactions or processes. [See SP 6.2] **LO 6.5** The student can, given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, K. [See SP 2.2] **LO 6.8** The student is able to use LeChatelier's principle to predict the direction of the shift resulting from various possible stresses on a system at chemical equilibrium. [See SP 1.4, 6.4] **LO 6.10** The student is able to connect LeChatelier's principle to the comparison of Q to K by explaining the effects of the stress on Q and K. [See SP 1.4, 7.2] **LO 6.13** The student can interpret titration data for monoprotic or polyprotic acids involving titration of a weak or strong acid by a strong base (or a weak or strong base by a strong acid) to determine the concentration of the titrant and the pKa for a weak acid, or the pKb for a weak base. [See SP 5.1, 6.4, connects to 1.E.2] **LO 6.16** The student can identify a given solution as being the solution of a monoprotic weak acid or base (including salts in which one ion is a weak acid or base), and calculate the pH and concentration of all species in the solution and/ or infer the relative strengths of the weak acids or bases from given equilibrium concentrations. [See SP 2.2, 6.4] **LO 6.17** The student can, given an arbitrary mixture of weak and strong acids and bases (including polyprotic systems), determine which species will react strongly with one another (i.e., with K >1), and what species will be present in large concentrations at equilibrium. [See SP 6.4]

2		**LO 2.6** The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [See SP 2.2, 2.3] **LO 3.4** The student is able to relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion. [See SP 2.2, 5.1, 6.4] **LO 4.9** The student is able to explain changes in reaction rates arising from the use of acid-base catalysts, surface catalysts, or enzyme catalysts, including selecting appropriate mechanisms with or without the catalyst present. [See SP 6.2, 7.2] **LO 5.8** The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds. [See SP 2.3, 7.1, 7.2] **LO 5.13** The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both ΔH° and ΔS°, and calculation or estimation of ΔG°when needed. [See SP 2.2, 2.3, 6.4, connects to 5.E.3]
3	except d	**LO 4.2** The student is able to analyze concentration vs. time data to determine the rate law for a zeroth-, first-, or second-order reaction. [See SP 5.1,6.4 connects to 4.A.3] **LO 4.7** The student is able to evaluate alternative explanations, as expressed by reaction mechanisms, to determine which are consistent with data regarding the overall rate of a reaction, and data that can be used to infer the presence of a reaction intermediate. [See SP 6.5, connects to 4.C.1, 4.C.2, 4.C.3] **LO 4.9** The student is able to explain changes in reaction rates arising from the use of acid-base catalysts, surface catalysts, or enzyme catalysts, including selecting appropriate mechanisms with or without the catalyst present. [See SP 6.2, 7.2]
4	except b and ci	**LO 1.18** The student is able to apply conservation of atoms to the rearrangement of atoms in various processes. [See SP 1.4] **LO 3.6** The student is able to use data from synthesis or decomposition of a compound to confirm the conservation of matter and the law of definite proportions. [See SP 2.2, 6.1] **LO 6.21** The student can predict the solubility of a salt, or rank the solubility of salts, given the relevant Ksp values. [See SP 2.2, 2.3, 6.4]

5	except e	**LO 3.4** The student is able to relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion. [See SP 2.2, 5.1, 6.4] **LO 6.21** The student can predict the solubility of a salt, or rank the solubility of salts, given the relevant Ksp values. [See SP 2.2, 2.3, 6.4] **LO 6.22** The student can interpret data regarding solubility of salts to determine, or rank, the relevant Ksp values. [See SP 2.2, 2.3, 6.4] **LO 3.12** The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faradays laws. [See SP 2.2, 2.3, 6.4] **LO 3.13** The student can analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions. [See SP 5.1]
6		**LO 1.9** The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model. [See SP 6.4] **LO 1.10** Students can justify with evidence the arrangement of the periodic table and can apply periodic properties to chemical reactivity. [See SP 6.1] **LO 2.21** The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]