

Version A

Name: _____

Period: _____

AP* Chemistry

NO CALCULATORS MAY BE USED

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	M	= molar
P	= pressure	m	= molal
V	= volume	L, mL	= liter(s), milliliter(s)
S	= entropy	g	= gram(s)
H	= enthalpy	nm	= nanometer(s)
G	= free energy	atm	= atmosphere(s)
R	= molar gas constant	J, kJ	= joule(s), kilojoule(s)
n	= number of moles	V	= volt(s)
mol	= mole(s)		

Part A

Directions: Each set of lettered choices below refers to the numbered questions or statements immediately following it. Select the one lettered choice that best answers each question or best fits each statement and then fill in the corresponding oval on the answer sheet. A choice may be used once, more than once, or not at all in each set. ***Before turning in your answer sheet, count the number of questions that you have skipped and place that number next to your name ON YOUR ANSWER SHEET and circle it.***

Questions 1-3 refer to the following types of elements in the periodic table.

- (A) Noble gases
- (B) Alkali metals
- (C) Halogens
- (D) Transition elements
- (E) Actinides

1. Are the most difficult to oxidize in a given period of the periodic table
2. Are always radioactive
3. Are the most likely to form anions

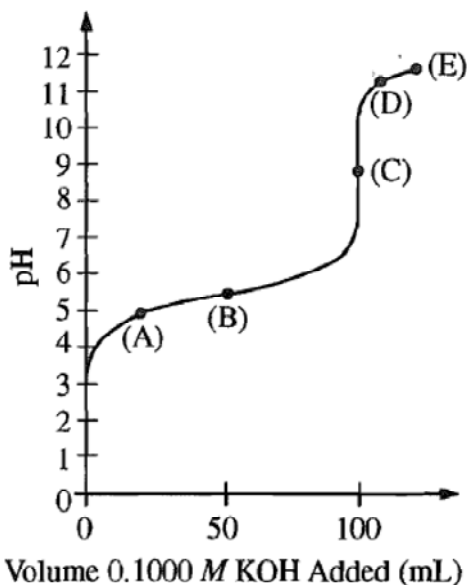
PERIODIC TABLE OF THE ELEMENTS

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

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

Questions 4-6

A solution of a weak monoprotic acid is titrated with a solution of a strong base, KOH. Consider the points labeled (A) through (E) on the titration curve that results, as shown below.



4. The point at which the moles of the added strong base are equal to the moles of the weak acid initially present.
5. The point at which the pH is closest to that of the strong base being added.
6. The point at which the concentrations of the weak acid and its conjugate base are approximately equal.

Questions 7-9 refer to the following pure substances, which are gases at 25°C and 1 atmosphere.

- (A) $\text{NH}_3(g)$
- (B) $\text{BH}_3(g)$
- (C) $\text{H}_2(g)$
- (D) $\text{H}_2\text{S}(g)$
- (E) $\text{HBr}(g)$

7. Has molecules with a pyramidal shape.
8. Is a strong electrolyte in aqueous solution
9. Is the slowest to effuse through a small opening at 25°C and 1 atm

Questions 10-11 refer to the following.

- (A) Activation energy
- (B) Enthalpy of formation
- (C) Entropy
- (D) Gibbs free energy
- (E) Lattice energy

10. Quantity would be zero for a pure, perfect crystal at 0 K.
11. Quantity typically determined by measuring the rate of a reaction at two or more different temperatures

Questions 12-14 refer to the following combinations of enthalpy changes (ΔH) and entropy changes (ΔS) for chemical reactions.

- (A) $\Delta H > 0, \Delta S > 0$
- (B) $\Delta H > 0, \Delta S < 0$
- (C) $\Delta H < 0, \Delta S > 0$
- (D) $\Delta H < 0, \Delta S < 0$
- (E) $\Delta H = 0, \Delta S < 0$

12. Must be true for a reaction that is spontaneous at all temperatures

Questions 15-17 refer to the following reactions.

- (A) $2 \text{Mg}(s) + \text{O}_2(g) \rightarrow 2 \text{MgO}(s)$
- (B) $\text{Pb}^{2+}(aq) + \text{CrO}_4^{2-}(aq) \rightarrow \text{PbCrO}_4(s)$
- (C) $\text{SO}_3(g) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{HSO}_4^-(aq)$
- (D) $2 \text{H}_2\text{O}(g) \rightarrow 2 \text{H}_2(g) + \text{O}_2(g)$
- (E) $\text{Ag}^+(aq) + 2 \text{NH}_3(aq) \rightarrow [\text{Ag}(\text{NH}_3)_2]^+(aq)$

15. A precipitation reaction
16. A Lewis acid-base reaction that produces a coordination complex
17. An oxidation-reduction reaction that is also a synthesis reaction

13. True for the evaporation of water at 25°C and 1 atm
14. True for the combustion of liquid pentane, $\text{C}_5\text{H}_{12}(l)$, to form $\text{H}_2\text{O}(g)$ and $\text{CO}_2(g)$ at 1 atm

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 oval on the answer sheet.

18.
$$2 \text{KClO}_3(s) \xrightarrow[\text{MnO}_2]{\Delta} 2 \text{KCl}(s) + 3 \text{O}_2(g)$$
- According to the equation above, how many moles of potassium chlorate, KClO_3 , must be decomposed to generate 1.0 L of O_2 gas at standard temperature and pressure?
- A) $\frac{1}{3} \left(\frac{1}{22.4} \right) \text{ mol}$
 B) $\frac{1}{2} \left(\frac{1}{22.4} \right) \text{ mol}$
 C) $\frac{2}{3} \left(\frac{1}{22.4} \right) \text{ mol}$
 D) $\frac{3}{2} \left(\frac{1}{22.4} \right) \text{ mol}$
 E) $2 \left(\frac{1}{22.4} \right) \text{ mol}$
19. Which of the following ions has the same number of electrons as Br^- ?
- A) Ca^{2+}
 B) K^+
 C) Sr^{2+}
 D) I^-
 E) Cl^-
20. In solid methane, the forces between neighboring CH_4 molecules are best characterized as
- A) ionic bonds
 B) covalent bonds
 C) hydrogen bonds
 D) ion-dipole forces
 E) London (dispersion) forces
21. Of the following electron configurations of neutral atoms, which represents an atom in an excited state?
- A) $1s^2 2s^2 2p^5$
 B) $1s^2 2s^2 2p^5 3s^2$
 C) $1s^2 2s^2 2p^6 3s^1$
 D) $1s^2 2s^2 2p^6 3s^2 3p^2$
 E) $1s^2 2s^2 2p^6 3s^2 3p^5$
22. Which of the following is a nonpolar molecule that contains polar bonds?
- A) F_2
 B) CHF_3
 C) CO_2
 D) HCl
 E) NH_3
23. The oxidation state that is common to aqueous ions of Fe, Mn, and Zn is
- A) +1
 B) +2
 C) +3
 D) +4
 E) +5
24. Which of the following shows the correct number of protons, neutrons, and electrons in a neutral cesium-134 atom?
- | | <u>Protons</u> | <u>Neutrons</u> | <u>Electrons</u> |
|----|----------------|-----------------|------------------|
| A) | 55 | 55 | 55 |
| B) | 55 | 79 | 55 |
| C) | 55 | 79 | 79 |
| D) | 79 | 55 | 79 |
| E) | 134 | 55 | 134 |

25. The pressure, in atm, exerted by 1.85 mol of an ideal gas placed in a 3.00 L container at 35.0°C is given by which of the following expressions?

- A) $\frac{(1.85)(0.0821)(308)}{3.00}$ atm
 B) $\frac{(1.85)(35.0)}{(0.0821)(3.00)}$ atm
 C) $\frac{3.00}{(1.85)(0.0821)(308)}$ atm
 D) $\frac{(1.85)(8.314)(308)}{3.00}$ atm
 E) $\frac{(3.00)(1.85)}{(0.0821)(35.0)}$ atm

26.

Experiment	$[X]_0$	$[Y]_0$	Initial Rate of Formation of Z (mol L ⁻¹ sec ⁻¹)
1	0.40	0.10	R
2	0.20	0.20	?

The table above shows the results from a rate study of the reaction $X + Y \rightarrow Z$. Starting with known concentrations of X and Y in experiment 1, the rate of formation of Z was measured. If the reaction was first ordered with respect to X and second with respect to Y, the initial rate of formation of Z in experiment 2 would be

- A) $\frac{R}{4}$
 B) $\frac{R}{2}$
 C) R
 D) $2R$
 E) $4R$

27. Which of the following is a correctly balanced nuclear reaction?

- A) ${}_{92}^{238}\text{U} \rightarrow {}_{90}^{232}\text{Th} + {}_2^4\text{He}$
 B) ${}_{98}^{249}\text{Cf} + {}_7^{15}\text{N} \rightarrow {}_{105}^{260}\text{Db} + 3{}_0^1\text{n}$
 C) ${}_1^2\text{H} + {}_1^3\text{H} \rightarrow {}_2^4\text{He} + 2{}_0^1\text{n}$
 D) ${}_{92}^{238}\text{U} + {}_0^1\text{n} \rightarrow {}_{92}^{239}\text{U}$
 E) ${}_{19}^{40}\text{K} \rightarrow {}_{20}^{40}\text{Ca} + {}_{+1}^0\beta$

28. Which of the following molecules contains only single bonds?
- A) CH_3COOH
 B) $\text{CH}_3\text{CH}_2\text{COOCH}_3$
 C) C_2H_6
 D) C_6H_6
 E) HCN
29. What is the molality of a solution of phosphoric acid, H_3PO_4 , that contains 24.5 g of phosphoric acid (molar mass 98.8 g) in 100. g of H_2O ?
- A) 0.245 *m*
 B) 2.50 *m*
 C) 4.00 *m*
 D) 25.0 *m*
 E) 40.0 *m*

30.

	Mass (g)
Empty flask	18.990
Flask + liquid	39.493

The density of a pure liquid at 25°C was calculated by determining the mass and volume of a sample of the liquid. A student measured the mass of a clean, dry 25.00 mL volumetric flask, filled the flask to its calibration mark with the liquid, and then measured the mass of the flask and liquid. The recorded measurements are shown in the table above. On the basis of this information, to how many significant figures should the density of the liquid be reported?

- A) 3
 B) 4
 C) 5
 D) 6
 E) 8
31. A compound contains 30. percent sulfur and 70. percent fluorine by mass. The empirical formula of the compound is
- A) SF
 B) SF_2
 C) SF_4
 D) SF_6
 E) S_2F
32. Gaseous cyclobutene undergoes a first-order reaction to form gaseous butadiene. At a particular temperature, the partial pressure of cyclobutene in the reaction vessel drops to one-eighth its original value in 124 seconds. What is the half-life for this reaction at this temperature?
- A) 15.5 sec
 B) 31.0 sec
 C) 41.3 sec
 D) 62.0 sec
 E) 124 sec

33. If 0.40 mol of H_2 and 0.15 mol of O_2 were to react as completely as possible to produce H_2O what mass of reactant would remain?

A) 0.20 g of H_2
 B) 0.40 g of H_2
 C) 3.2 g of O_2
 D) 4.0 g of O_2
 E) 4.4 g of O_2

34.



When the equation above is balanced and all coefficients are reduced to lowest whole-number terms, what is the coefficient for $\text{H}_3\text{PO}_4(l)$?

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

35.



Which of the following changes to the equilibrium system represented above will increase the quantity of $\text{HI}(g)$ in the equilibrium mixture?

- I. Adding $\text{H}_2(g)$
 II. Increasing the temperature
 III. Decreasing the pressure

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

36. How many carbon atoms are contained in 2.8 g of C_2H_4 ?

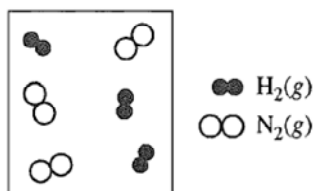
A) 1.2×10^{23}
 B) 3.0×10^{23}
 C) 6.0×10^{23}
 D) 1.2×10^{24}
 E) 6.0×10^{24}

37. Which of the following elements combines with oxygen to form a covalent network solid?

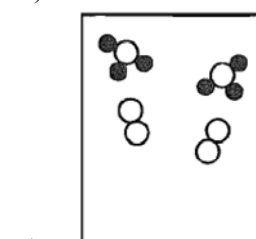
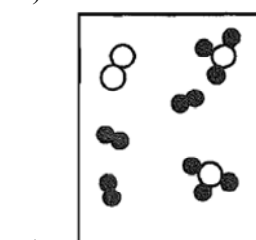
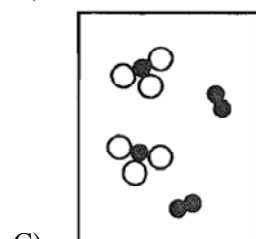
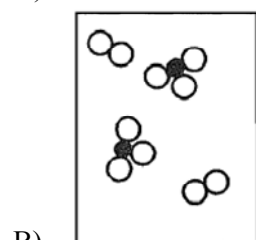
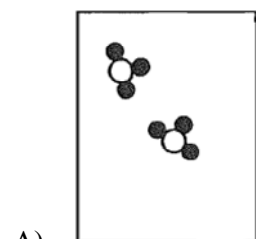
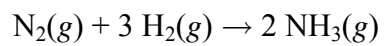
A) Si
 B) S
 C) C
 D) Mg
 E) Cs

38. How many mL of 10.0 *M* HCl are needed to prepare 500.mL of 2.00 *M* HCl?
- A) 1.00 mL
 - B) 10.0 mL
 - C) 20.0 mL
 - D) 100. mL
 - E) 200. mL
39. A student mixes equal volumes of 1.0 *M* solutions of tin(II) chloride and copper(II) sulfate and observes that no precipitate forms. The student mixes equal volumes of 1.0 *M* solutions of zinc(II) sulfate and tin(II) fluoride and observes the formation of a precipitate. The formula of the precipitate must be
- A) SnF₂
 - B) SnSO₄
 - C) Sn(SO₄)₂
 - D) ZnF
 - E) ZnF₂
40. On the basis of strength of intermolecular forces, which of the following elements would be expected to have the highest melting point?
- A) Br₂
 - B) Cl₂
 - C) F₂
 - D) Kr
 - E) N₂

41.



The diagram above represents $\text{H}_2(g)$ and $\text{N}_2(g)$ in a closed container. Which of the following diagrams would represent the results if the reaction shown below were to proceed as far as possible?



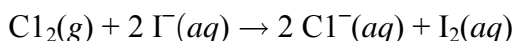
42. Equal masses of He and Ne are placed in a sealed container. What is the partial pressure of He if the total pressure in the container is 6 atm?

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

43. A pure liquid in an open vessel boils at the temperature at which the

A) molar entropy of the liquid becomes equal to that of the gas
 B) vapor pressure of the liquid becomes equal to the equilibrium pressure at the triple point
 C) vapor pressure of the liquid becomes equal to the atmospheric pressure on the surface of the liquid
 D) molar heat capacity of the liquid becomes equal to that of the gas
 E) average kinetic energy of the liquid molecules becomes equal to that of the gas molecules

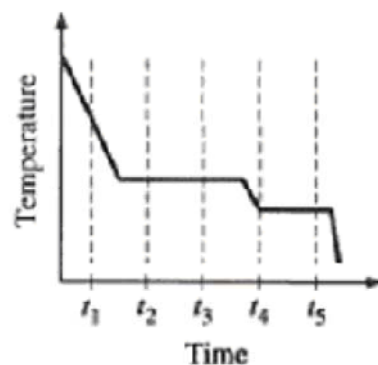
44.



Which of the following best accounts for the fact that a galvanic cell based on the reaction represented above will generate electricity?

A) Cl_2 can easily lose two electrons.
 B) Cl_2 is a stronger oxidizing agent than I_2 .
 C) I atoms have more electrons than do atoms of Cl.
 D) I^- is a more stable species than I_2 .
 E) $\text{I}_2(s)$ is more soluble than $\text{Cl}_2(g)$.

45.



The cooling curve above shows how the temperature of a sample varies with time as the sample goes through phase changes. The sample starts as a gas, and heat is removed at a constant rate. At which time does the sample contain the most liquid?

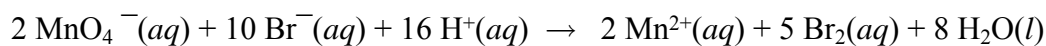
A) t_1
 B) t_2
 C) t_3
 D) t_4
 E) t_5

46. A solution is prepared by adding 16 g of CH_3OH (molar mass 32 g) to 90. g of H_2O (molar mass 18 g). The mole fraction of CH_3OH in this solution is closest to which of the following?

A) 0.1
 B) 0.2
 C) 0.3
 D) 0.4
 E) 0.6

47. When diluting concentrated H_2SO_4 , one should slowly add acid to a beaker of water rather than add water to a beaker of acid. The reason for this precaution is to ensure that
- there is complete ionization of the H_2SO_4
 - there is a sufficient volume of water to absorb the heat released
 - the water does not sink beneath the acid and remain unmixed
 - the acid does not react with impurities in the dry beaker
 - any SO_2 released quickly redissolves in the water
48. Which of the following is the conjugate acid of NH_2^- ?
- NH_2^-
 - NH_3
 - H^+
 - NH_4^+
 - H_2O
49. Salts containing which of the following ions are generally insoluble in cold water?
- Acetate
 - Ammonium
 - Potassium
 - Nitrate
 - Phosphate

50.



How many electrons are transferred in the reaction represented by the balanced equation above?

- 2
 - 4
 - 5
 - 8
 - 10
51. Under which of the following conditions of temperature and pressure would 1.0 mol of the real gas $\text{CO}_2(g)$ behave most like an ideal gas?
- | | Temperature
(K) | Pressure
(atm) |
|----|--------------------|-------------------|
| A) | 100 | 0.1 |
| B) | 100 | 100 |
| C) | 800 | 0.1 |
| D) | 800 | 1 |
| E) | 800 | 100 |
52. Which of the following measures of concentration changes with temperature?
- Mass percentage
 - Mole fraction
 - Molarity
 - Molality
 - Parts per million by mass

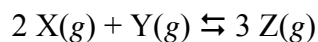
53. A sample of 10.0 mol of butyric acid, $\text{HC}_4\text{H}_7\text{O}_2$, a weak acid, is dissolved in 1000. g of water to make a 10.0-molal solution. Which of the following would be the best method to determine the molarity of the solution? (In each case, assume that no additional information is available.)

A) Titration of the solution with standard acid
 B) Measurement of the pH with a pH meter
 C) Determination of the freezing point of the solution
 D) Measurement of the total volume of the solution
 E) Measurement of the electrical conductivity of the solution

54. The nonvolatile compound ethylene glycol, $\text{C}_2\text{H}_6\text{O}_2$, forms nearly ideal solutions with water. What is the vapor pressure of a solution made from 1.00 mole of $\text{C}_2\text{H}_6\text{O}_2$ and 9.00 moles of H_2O if the vapor pressure of pure water at the same temperature is 25.0 mm Hg?

A) 2.50 mm Hg
 B) 7.50 mm Hg
 C) 12.5 mm Hg
 D) 22.5 mm Hg
 E) 27.5 mm Hg

55.



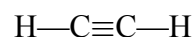
The reaction mixture represented above is at equilibrium at 298 K, and the molar concentrations are $[\text{X}] = 2.0 \text{ M}$, $[\text{Y}] = 0.5 \text{ M}$, and $[\text{Z}] = 4.0 \text{ M}$. What is the value of the equilibrium constant for the reaction at 298K?

A) 0.50
 B) 2.0
 C) 4.0
 D) 16
 E) 32

56. The London (dispersion) forces are weakest for which of the following gases under the same conditions of temperature and pressure?

A) H_2
 B) O_2
 C) Xe
 D) F_2
 E) N_2

57.



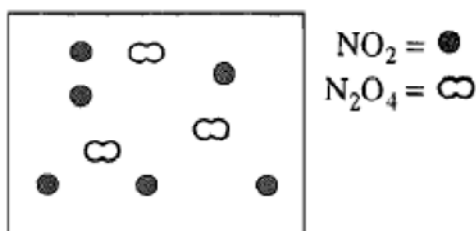
What is the hybridization of the carbon atoms in a molecule of ethyne, represented above?

A) sp
 B) sp^2
 C) sp^3
 D) dsp^2
 E) d^2sp

58. A 360. mg sample of aspirin, $\text{C}_9\text{H}_8\text{O}_4$, (molar mass 180. g), is dissolved in enough water to produce 200. mL of solution. What is the molarity of aspirin in a 50. mL sample of this solution?

A) 0.0800 M
 B) 0.0400 M
 C) 0.0200 M
 D) 0.0100 M
 E) 0.00250 M

59.

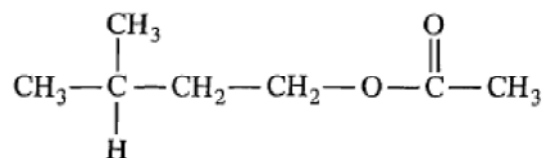


The diagram above represents a mixture of $\text{NO}_2(g)$ and $\text{N}_2\text{O}_4(g)$ in a 1.0 L container at a given temperature. The two gases are in equilibrium according to the equation $2 \text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)$.

Which of the following must be true about the value of the equilibrium constant for the reaction at this temperature?

- A) $K = 0$
 - B) $0 < K < 1$
 - C) $K = 1$
 - D) $K > 1$
 - E) There is not enough information to determine the relative value of K .
60. When aqueous NH_3 is first added to a solution containing Ni^{2+} , a precipitate forms, but when an excess of aqueous NH_3 is added, the precipitate dissolves. Which of the following best explains why the precipitate dissolves?
- A) Ni^{2+} forms hydrogen bonds with NH_3 .
 - B) Ni^{2+} forms a complex ion with NH_3 .
 - C) Ni^{2+} acts as a Bronsted-Lowry base.
 - D) Ni^{2+} is oxidized to Ni^{3+} .
 - E) Ni^{2+} is reduced to Ni^+ .

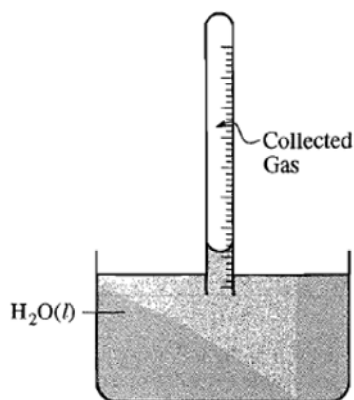
61.



The structure of a molecule of "banana oil" is shown above. This organic compound is an example of

- A) an alcohol
 - B) an amine
 - C) a carboxylic acid
 - D) an ester
 - E) a ketone
62. Which of the following pieces of laboratory glassware should be used to most accurately measure out a 25.00 mL sample of a solution?
- A) 5 mL pipet
 - B) 25 mL pipet
 - C) 25 mL beaker
 - D) 25 mL Erlenmeyer flask
 - E) 50 mL graduated cylinder
63. Which of the following best helps to account for the fact that the F^- ion is smaller than the O^{2-} ion?
- A) F^- has a larger nuclear mass than O^{2-} has.
 - B) F^- has a larger nuclear charge than O^{2-} has.
 - C) F^- has more electrons than O^{2-} has.
 - D) F^- is more electronegative than O^{2-} is.
 - E) F^- is more polarizable than O^{2-} is.
64. Which of the following solutions has a pH greater than 7.0?
- A) 0.10 M KBr
 - B) 0.10 M NH_4Cl
 - C) 0.10 M $\text{HC}_2\text{H}_3\text{O}_2$
 - D) 0.10 M NaF
 - E) 0.10 M HI

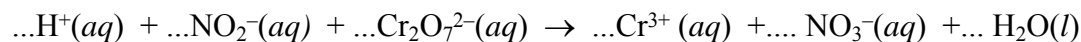
65.



In a laboratory experiment, $\text{H}_2(g)$ is collected over water in a gas-collection tube as shown in the diagram above. The temperature of the water is 21°C and the atmospheric pressure in the laboratory is measured to be 772 torr. Before measuring the volume of gas collected what step, if any must be taken to make it possible to determine the total gas pressure inside the tube?

- A) Tilt the tube to the side enough to let some air in to break the partial vacuum in the tube.
- B) Lift the tube upward until it is just barely immersed in the water.
- C) Move the tube downward until the water level is the same inside and outside the tube.
- D) Adjust the temperature of the water to 25°C .
- E) No further steps need to be taken as long as the temperature of the water is known.

67.



When the equation above is balanced and all coefficients are reduced to lowest whole-number terms, the coefficient for $\text{H}_2\text{O}(l)$ is

- A) 2
- B) 4
- C) 5
- D) 6
- E) 8

66. Factors that affect the rate of a chemical reaction include which of the following?

- I. Frequency of collisions of reactant particles
- II. Kinetic energy of collisions of reactant particles
- III. Orientation of reactant particles during collisions

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

68. The pH of a solution prepared by the addition of 10. mL of 0.002 M KOH(aq) to 10. mL of distilled water is closest to

A) 12
B) 11
C) 10
D) 4
E) 3

69. At standard temperature and pressure, a 0.50 mol sample of H₂ gas and a separate 1.0 mol sample of O₂ gas have the same

A) average molecular kinetic energy
B) average molecular speed
C) volume
D) effusion rate
E) density

70. Naturally produced amino acids typically contain all of the following elements EXCEPT

A) nitrogen
B) chlorine
C) oxygen
D) hydrogen
E) carbon

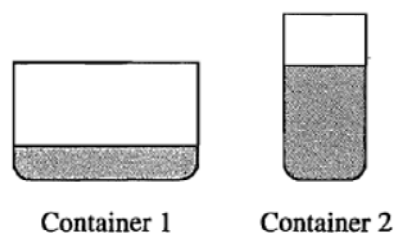
71. Of the following single bonds, which is the LEAST polar?

A) N – H
B) H – F
C) O – F
D) I – F
E) O – H

72. When mixed, each of the following pairs of reactants gives visible evidence of a chemical reaction EXCEPT

A) Na₂CO₃(s) + HCl(aq)
B) Zn(s) + HCl(aq)
C) Ba(NO₃)₂(aq) + Na₂SO₄(aq)
D) FeCl₃(aq) + KOH(aq)
E) NH₄Cl(aq) + HCl(aq)

73.



The figure above shows two closed containers. Each contains the same volume of acetone in equilibrium with its vapor at the same temperature. The vapor pressure of the acetone is

- A) higher in container 1 because the surface area of the liquid is greater
B) higher in container 1 because the volume of vapor is greater
C) lower in container 1 because the level of the liquid is lower
D) the same in both containers because the volume of the liquid is the same
E) the same in both containers because the temperature is the same

74. An electric current of 1.00 ampere is passed through an aqueous solution of $\text{Ni}(\text{NO}_3)_2$. How long will it take to plate out exactly 1.00 mol of nickel metal, assuming 100 percent current efficiency?

(1 faraday = 96,500 coulombs = 6.02×10^{23} electrons)

- A) 386,000 sec
 - B) 193,000 sec
 - C) 96,500 sec
 - D) 48,200 sec
 - E) 24,100 sec
75. Which of the following molecules has an angular (bent) geometry that is commonly represented as a resonance hybrid of two or more electron-dot structures?
- A) CO_2
 - B) O_3
 - C) CH_4
 - D) BeF_2
 - E) OF_2

Chapter III: Answers to the 2008 AP Chemistry Exam

■ Section I: Multiple Choice

- Section I Answer Key and Percent Answering Correctly
- Analyzing Your Students' Performance on the Multiple-Choice Section
- Diagnostic Guide for the 2008 AP Chemistry Exam

■ Section II: Free Response

- Comments from the Chief Reader
- Scoring Guidelines, Sample Student Responses, and Commentary

Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions, the percent of AP students who answered each question correctly by AP score, and the total percent answering correctly.

Section I Answer Key and Percent Answering Correctly

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
1	A	87	82	77	70	54	72
2	E	94	85	75	65	45	70
3	C	89	81	69	58	37	63
4	C	91	76	66	58	46	65
5	E	95	86	76	65	42	69
6	B	74	45	32	25	22	38
7	A	91	79	69	62	51	68
8	E	85	67	51	38	25	50
9	E	90	79	67	55	35	62
10	C	69	52	41	33	21	41
11	A	56	36	29	26	23	33
12	C	93	79	62	45	25	57
13	A	81	57	39	26	16	41
14	C	71	47	32	21	13	34
15	B	99	96	91	83	52	80
16	E	87	72	58	47	37	58
17	A	91	75	56	40	24	54
18	C	85	72	63	57	43	62
19	C	99	95	89	78	48	78
20	E	87	66	48	33	16	46
21	B	95	88	79	68	42	71
22	C	75	50	36	26	19	39
23	B	97	92	87	80	64	82
24	B	98	94	89	80	60	82
25	A	98	95	93	89	71	87

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
26	D	87	65	45	31	21	47
27	D	91	81	73	64	48	69
28	C	96	91	84	76	52	77
29	B	82	65	48	31	18	46
30	B	77	63	54	48	37	54
31	C	90	81	70	59	39	65
32	C	73	53	37	26	14	38
33	A	93	77	58	41	26	56
34	D	94	89	85	80	61	80
35	C	86	71	57	46	33	56
36	A	71	45	29	22	17	35
37	A	81	61	45	32	17	44
38	D	96	90	81	70	47	73
39	E	82	71	64	54	35	58
40	A	67	40	27	22	19	33
41	E	84	66	53	43	29	52
42	E	69	44	25	13	5	29
43	C	83	67	54	41	28	52
44	B	82	61	46	36	25	48
45	D	90	75	61	48	30	57
46	A	93	84	71	55	26	61
47	B	49	34	27	23	18	29
48	B	91	80	70	59	38	64
49	E	81	66	53	41	24	50
50	E	80	50	30	17	8	34

continued on the next page

Section I Answer Key and Percent Answering Correctly *(continued)*

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
51	C	73	51	37	25	15	37
52	C	69	51	39	30	23	40
53	D	88	77	67	58	42	64
54	D	54	26	15	10	9	21
55	E	94	87	80	68	35	69
56	A	78	52	38	29	21	41
57	A	74	51	35	22	11	36
58	D	67	42	30	22	14	33
59	B	63	43	31	22	14	32
60	B	68	42	28	21	15	33
61	D	58	39	30	24	19	32
62	B	47	38	32	29	22	32
63	B	80	55	36	23	12	38

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
64	D	72	44	28	20	13	33
65	C	62	52	45	39	29	43
66	E	80	64	53	44	32	52
67	B	49	22	13	10	11	20
68	B	56	30	18	14	11	24
69	A	81	63	47	36	23	47
70	B	92	85	78	73	60	76
71	C	75	59	47	35	23	45
72	E	74	57	46	37	24	45
73	E	44	24	19	17	14	23
74	B	69	33	13	7	9	24
75	B	79	56	40	29	16	41

Analyzing Your Students' Performance on the Multiple-Choice Section

If you give your students the 2008 exam for practice, you may want to analyze the results to find overall strengths and weaknesses in their understanding of AP Chemistry. The following diagnostic worksheet will help you do this. You are permitted to photocopy and distribute it to your students for completion.

1. In each section, students should insert a check mark for each correct answer.
2. Add together the total number of correct answers for each section.

3. To compare the student's number of correct answers for each section with the average number correct for that section, copy the number of correct answers to the "Number Correct" table at the end of the Diagnostic Guide.

In addition, under each item, the percent of AP students who answered correctly is shown, so students can analyze their performance on individual items. This information will be helpful in deciding how students should plan their study time. Please note that one item may appear in several different categories, as questions can cover different topics.



Multiple Choice Diagnostics Guide for the 2008 AP* Chemistry Exam

Place a ✓ in the box below the question number if you answered the question correctly.
Place a ✗ in the box below the question number if you answered the question incorrectly.
YOU SHOULD NOT HAVE SKIPPED ANY QUESTIONS! If you did, leave the box blank.
Award yourself one point for each correct answer and calculate your section averages and compare them to the national average.

Compare your answers to the “% of Students Answering Correctly”. If 50+% of the testing population answered correctly, you should as well! If your incorrect responses pile up in any one section, then you need to study that topic. Performing this analysis will help you target your areas of weakness and better structure your remaining study time. Remember your goal is to get at least 75% of the points (56.25 points in this case).

Please note that one item may appear in several different categories, as questions can cross over different topics.

Structure of Matter/Atomic Theory & Atomic Structure (Average number correct 5.6 out of 8)

Question #	1	2	3	19	21	23	24	63
Correct or Incorrect								
% of Students Answering Correctly	72	70	63	78	71	82	82	38

Structure of Matter/Chemical Bonding (Average number correct 3.1 out of 6)

Question #	7	22	28	37	57	71
Correct or Incorrect						
% of Students Answering Correctly	68	39	77	44	36	45

Structure of Matter/Nuclear Chemistry (Average number correct 0.7 out of 1)

Question #	27
Correct or Incorrect	
% of Students Answering Correctly	69

Structure of Matter/Gases (Average number correct 3.1 out of 6)

Question #	9	25	42	51	65	69
Correct or Incorrect						
% of Students Answering Correctly	62	87	29	37	43	47

States of Matter/Liquids and Solids (Average number correct 2.2 out of 5)

Question #	20	40	43	56	73
Correct or Incorrect					
% of Students Answering Correctly	67	33	52	41	23

States of Matter/Solutions (Average number correct 3.3 out of 8)

Question #	8	29	43	52	53	54	58	73
Correct or Incorrect								
% of Students Answering Correctly	50	46	52	40	64	21	33	23

Reactions/Reaction Types (Average number correct 4.4 out of 8)

Question #	15	16	17	34	39	49	50	60
Correct or Incorrect								
% of Students Answering Correctly	80	54	54	80	58	50	34	33

Reactions/Stoichiometry (Average number correct 5.2 out of 9)

Question #	18	31	33	34	36	38	41	46	58
Correct or Incorrect									
% of Students Answering Correctly	62	65	56	80	35	73	52	61	33

Reactions/Equilibrium (Average number correct 1.9 out of 6)

Question #	18	45	49	55	59	73
Correct or Incorrect						
% of Students Answering Correctly	62	57	50	69	32	23

Reactions/Kinetics (Average number correct 2.1 out of 5)

Question #	11	15	26	32	66
Correct or Incorrect					
% of Students Answering Correctly	33	38	47	38	52

Reactions/Thermodynamics (Average number correct 3.2 out of 7)

Question #	10	11	12	13	14	18	69
Correct or Incorrect							
% of Students Answering Correctly	41	33	57	41	34	62	47

Descriptive Chemistry (Average number correct 6.2 out of 11)

Question #	1	2	3	8	16	23	37	60	61	70	72
Correct or Incorrect											
% of Students Answering Correctly	72	70	63	50	54	82	44	33	32	76	45

Laboratory (Average number correct 2.5 out of 5)

Question #	30	39	53	62	65
Correct or Incorrect					
% of Students Answering Correctly	54	58	64	32	43

Quantitative* (Average number correct 8.5 out of 17)

Question #	18	25	26	29	31	32	33	36	38	42	46	53	55	58	59	68	74
75Correct or Incorrect																	
% of Students Answering Correctly	62	87	47	46	65	38	56	35	73	29	61	64	69	33	32	24	24

***Problems using simple numbers or simple quantitative reasoning are not included in this list.**



AP[®] Chemistry 2008 Free-Response Questions

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DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

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

STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

Half-reaction			$E^\circ(\text{V})$
$\text{F}_2(\text{g}) + 2\text{e}^-$	\rightarrow	2F^-	2.87
$\text{Co}^{3+} + \text{e}^-$	\rightarrow	Co^{2+}	1.82
$\text{Au}^{3+} + 3\text{e}^-$	\rightarrow	$\text{Au}(\text{s})$	1.50
$\text{Cl}_2(\text{g}) + 2\text{e}^-$	\rightarrow	2Cl^-	1.36
$\text{O}_2(\text{g}) + 4\text{H}^+ + 4\text{e}^-$	\rightarrow	$2\text{H}_2\text{O}(\text{l})$	1.23
$\text{Br}_2(\text{l}) + 2\text{e}^-$	\rightarrow	2Br^-	1.07
$2\text{Hg}^{2+} + 2\text{e}^-$	\rightarrow	Hg_2^{2+}	0.92
$\text{Hg}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Hg}(\text{l})$	0.85
$\text{Ag}^+ + \text{e}^-$	\rightarrow	$\text{Ag}(\text{s})$	0.80
$\text{Hg}_2^{2+} + 2\text{e}^-$	\rightarrow	$2\text{Hg}(\text{l})$	0.79
$\text{Fe}^{3+} + \text{e}^-$	\rightarrow	Fe^{2+}	0.77
$\text{I}_2(\text{s}) + 2\text{e}^-$	\rightarrow	2I^-	0.53
$\text{Cu}^+ + \text{e}^-$	\rightarrow	$\text{Cu}(\text{s})$	0.52
$\text{Cu}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Cu}(\text{s})$	0.34
$\text{Cu}^{2+} + \text{e}^-$	\rightarrow	Cu^+	0.15
$\text{Sn}^{4+} + 2\text{e}^-$	\rightarrow	Sn^{2+}	0.15
$\text{S}(\text{s}) + 2\text{H}^+ + 2\text{e}^-$	\rightarrow	$\text{H}_2\text{S}(\text{g})$	0.14
$2\text{H}^+ + 2\text{e}^-$	\rightarrow	$\text{H}_2(\text{g})$	0.00
$\text{Pb}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Ni}(\text{s})$	-0.25
$\text{Co}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Co}(\text{s})$	-0.28
$\text{Cd}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Cd}(\text{s})$	-0.40
$\text{Cr}^{3+} + \text{e}^-$	\rightarrow	Cr^{2+}	-0.41
$\text{Fe}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Fe}(\text{s})$	-0.44
$\text{Cr}^{3+} + 3\text{e}^-$	\rightarrow	$\text{Cr}(\text{s})$	-0.74
$\text{Zn}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Zn}(\text{s})$	-0.76
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^-$	\rightarrow	$\text{H}_2(\text{g}) + 2\text{OH}^-$	-0.83
$\text{Mn}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Mn}(\text{s})$	-1.18
$\text{Al}^{3+} + 3\text{e}^-$	\rightarrow	$\text{Al}(\text{s})$	-1.66
$\text{Be}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Be}(\text{s})$	-1.70
$\text{Mg}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Mg}(\text{s})$	-2.37
$\text{Na}^+ + \text{e}^-$	\rightarrow	$\text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Ca}(\text{s})$	-2.87
$\text{Sr}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Sr}(\text{s})$	-2.89
$\text{Ba}^{2+} + 2\text{e}^-$	\rightarrow	$\text{Ba}(\text{s})$	-2.90
$\text{Rb}^+ + \text{e}^-$	\rightarrow	$\text{Rb}(\text{s})$	-2.92
$\text{K}^+ + \text{e}^-$	\rightarrow	$\text{K}(\text{s})$	-2.92
$\text{Cs}^+ + \text{e}^-$	\rightarrow	$\text{Cs}(\text{s})$	-2.92
$\text{Li}^+ + \text{e}^-$	\rightarrow	$\text{Li}(\text{s})$	-3.05

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

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

$$\lambda = \frac{h}{m\nu} \quad p = m\nu$$

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

EQUILIBRIUM

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

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

$$K_w = [\text{OH}^-][\text{H}^+] = 1.0 \times 10^{-14} \text{ @ } 25^\circ\text{C}$$

$$= K_a \times K_b$$

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

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

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

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

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

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

where Δn = moles product gas – moles reactant gas

THERMOCHEMISTRY/KINETICS

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

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

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

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$= -RT \ln K = -2.303 RT \log K$$

$$= -n\mathcal{F}E^\circ$$

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

$$q = mc\Delta T$$

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

$$\ln[A]_t - \ln[A]_0 = -kt$$

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

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

$$E = \text{energy} \quad v = \text{velocity}$$

$$\nu = \text{frequency} \quad n = \text{principal quantum number}$$

$$\lambda = \text{wavelength} \quad m = \text{mass}$$

$$p = \text{momentum}$$

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

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

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

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

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

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

Equilibrium Constants

$$K_a \text{ (weak acid)}$$

$$K_b \text{ (weak base)}$$

$$K_w \text{ (water)}$$

$$K_p \text{ (gas pressure)}$$

$$K_c \text{ (molar concentrations)}$$

$$S^\circ = \text{standard entropy}$$

$$H^\circ = \text{standard enthalpy}$$

$$G^\circ = \text{standard free energy}$$

$$E^\circ = \text{standard reduction potential}$$

$$T = \text{temperature}$$

$$n = \text{moles}$$

$$m = \text{mass}$$

$$q = \text{heat}$$

$$c = \text{specific heat capacity}$$

$$C_p = \text{molar heat capacity at constant pressure}$$

$$E_a = \text{activation energy}$$

$$k = \text{rate constant}$$

$$A = \text{frequency factor}$$

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

$$\text{Gas constant, } R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$$

$$= 62.4 \text{ L torr mol}^{-1} \text{ K}^{-1}$$

$$= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$$

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

$$P_{total} = P_A + P_B + P_C + \dots$$

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

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

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

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

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

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

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

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

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

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

$$\pi = iMRT$$

$$A = abc$$

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

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

OXIDATION-REDUCTION; ELECTROCHEMISTRY

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

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

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

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

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 $\text{H}_2\text{O} = 1.86 \text{ K kg mol}^{-1}$

K_b for $\text{H}_2\text{O} = 0.512 \text{ K kg mol}^{-1}$

$1 \text{ atm} = 760 \text{ mm Hg}$

$= 760 \text{ torr}$

$\text{STP} = 0.00^\circ\text{C}$ and 1.0 atm

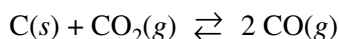
Faraday's constant, $\mathcal{F} = 96,500 \text{ coulombs per mole of electrons}$

2008 AP[®] CHEMISTRY FREE-RESPONSE QUESTIONS**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 the booklet with the pink cover. Do NOT write your answers on the green insert.

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



1. Solid carbon and carbon dioxide gas at 1,160 K were placed in a rigid 2.00 L container, and the reaction represented above occurred. As the reaction proceeded, the total pressure in the container was monitored. When equilibrium was reached, there was still some C(s) remaining in the container. Results are recorded in the table below.

Time (hours)	Total Pressure of Gases in Container at 1,160 K (atm)
0.0	5.00
2.0	6.26
4.0	7.09
6.0	7.75
8.0	8.37
10.0	8.37

- (a) Write the expression for the equilibrium constant, K_p , for the reaction.
- (b) Calculate the number of moles of $\text{CO}_2(g)$ initially placed in the container. (Assume that the volume of the solid carbon is negligible.)

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- (c) For the reaction mixture at equilibrium at 1,160 K, the partial pressure of the $\text{CO}_2(g)$ is 1.63 atm. Calculate
- (i) the partial pressure of $\text{CO}(g)$, and
 - (ii) the value of the equilibrium constant, K_p .
- (d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of $\text{C}(s)$, plus $\text{CO}(g)$ and $\text{CO}_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

- (e) Predict whether the partial pressure of $\text{CO}_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.
-

2008 AP® CHEMISTRY FREE-RESPONSE QUESTIONS

2. Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $\text{MgCl}_2 \cdot n \text{H}_2\text{O}$. The student collects the data shown in the following table.

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

- (a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.
- (b) Use the data above to
- (i) calculate the total number of moles of water lost when the sample was heated, and
 - (ii) determine the formula of the hydrated compound.
- (c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

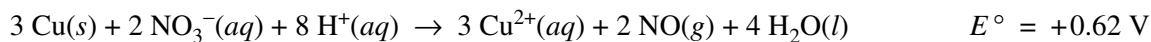
In the second experiment, a student is given 2.94 g of a mixture containing anhydrous MgCl_2 and KNO_3 . To determine the percentage by mass of MgCl_2 in the mixture, the student uses excess $\text{AgNO}_3(aq)$ to precipitate the chloride ion as $\text{AgCl}(s)$.

- (d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.
- (e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.
- (i) The number of moles of MgCl_2 in the original mixture
 - (ii) The percent by mass of MgCl_2 in the original mixture

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3. Answer the following questions related to chemical reactions involving nitrogen monoxide, NO(g).

The reaction between solid copper and nitric acid to form copper(II) ion, nitrogen monoxide gas, and water is represented by the following equation.

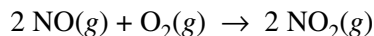


- (a) Using the information above and in the table below, calculate the standard reduction potential, E° , for the reduction of NO_3^- in acidic solution.

Half-Reaction	Standard Reduction Potential, E°
$\text{Cu}^{2+}(aq) + 2 e^- \rightarrow \text{Cu}(s)$	+0.34 V
$\text{NO}_3^-(aq) + 4 \text{ H}^+(aq) + 3 e^- \rightarrow \text{NO}(g) + 2 \text{ H}_2\text{O}(l)$?

- (b) Calculate the value of the standard free energy change, ΔG° , for the overall reaction between solid copper and nitric acid.
- (c) Predict whether the value of the standard entropy change, ΔS° , for the overall reaction is greater than 0, less than 0, or equal to 0. Justify your prediction.

Nitrogen monoxide gas, a product of the reaction above, can react with oxygen to produce nitrogen dioxide gas, as represented below.



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A rate study of the reaction yielded the data recorded in the table below.

Experiment	Initial Concentration of NO (mol L ⁻¹)	Initial Concentration of O ₂ (mol L ⁻¹)	Initial Rate of Formation of NO ₂ (mol L ⁻¹ s ⁻¹)
1	0.0200	0.0300	8.52×10^{-2}
2	0.0200	0.0900	2.56×10^{-1}
3	0.0600	0.0300	7.67×10^{-1}

- (d) Determine the order of the reaction with respect to each of the following reactants. Give details of your reasoning, clearly explaining or showing how you arrived at your answers.
- (i) NO
 - (ii) O₂
- (e) Write the expression for the rate law for the reaction as determined from the experimental data.
- (f) Determine the value of the rate constant for the reaction, clearly indicating the units.

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.**

2008 AP[®] CHEMISTRY FREE-RESPONSE QUESTIONS**CHEMISTRY****Part B****Time—40 minutes****NO CALCULATORS MAY BE USED FOR PART B.**

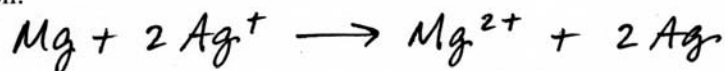
Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. 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 graded.

EXAMPLE:

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

(i) Balanced equation:



(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

- (a) Aqueous sodium hydroxide is added to a saturated solution of aluminum hydroxide, forming a complex ion.

(i) Balanced equation:

(ii) If the resulting mixture is acidified, would the concentration of the complex ion increase, decrease, or remain the same? Explain.

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(b) Hydrogen chloride gas is oxidized by oxygen gas.

(i) Balanced equation:

(ii) If three moles of hydrogen chloride gas and three moles of oxygen gas react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

(c) Solid potassium oxide is added to water.

(i) Balanced equation:

(ii) If a few drops of phenolphthalein are added to the resulting solution, what would be observed? Explain.

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

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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 graded 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. Using principles of atomic and molecular structure and the information in the table below, answer the following questions about atomic fluorine, oxygen, and xenon, as well as some of their compounds.

Atom	First Ionization Energy (kJ mol ⁻¹)
F	1,681.0
O	1,313.9
Xe	?

- (a) Write the equation for the ionization of atomic fluorine that requires 1,681.0 kJ mol⁻¹.
- (b) Account for the fact that the first ionization energy of atomic fluorine is greater than that of atomic oxygen. (You must discuss both atoms in your response.)
- (c) Predict whether the first ionization energy of atomic xenon is greater than, less than, or equal to the first ionization energy of atomic fluorine. Justify your prediction.

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- (d) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4 . In the boxes provided, draw the complete Lewis electron-dot diagram for each of the molecules represented below.

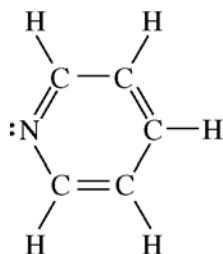


- (e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:
- (i) The geometric shape of the XeO_3 molecule
 - (ii) The hybridization of the valence orbitals of xenon in XeF_4
- (f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

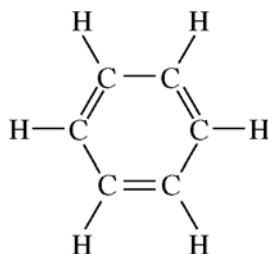
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6. Answer the following questions by using principles of molecular structure and intermolecular forces.

- (a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water, whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.

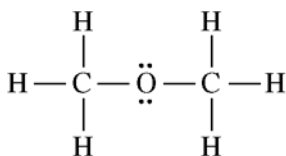


Pyridine

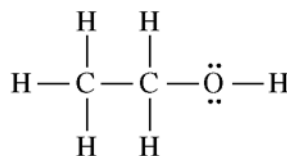


Benzene

- (b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.



Dimethyl Ether



Ethanol

- (c) SO₂ melts at 201 K, whereas SiO₂ melts at 1,883 K. Account for the difference in melting points. You must discuss both of the substances in your answer.
- (d) The normal boiling point of Cl₂(*l*) (238 K) is higher than the normal boiling point of HCl(*l*) (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

STOP

END OF EXAM

**AP* Chemistry: 2008 Released Multiple Choice Exam
Answer Section****OTHER**

1. ANS:
A

Don't let the "oxidize" throw you off! It's just a fancy way of saying "react" which you know to be those pesky noble gases that resist participating in chemical reactions of any sort.

DIF: Easy MSC: 2008 #1 NOT: 72% answered correctly

2. ANS:
E

You're looking looking for elements that are man made. Those would be the rare earth metals that make up the *f* block of the periodic table.

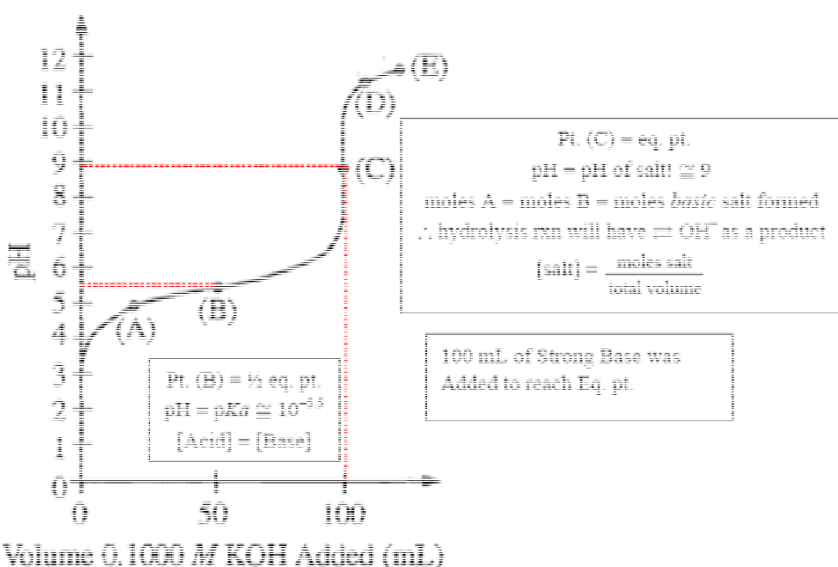
DIF: Easy MSC: 2008 #2 NOT: 70% answered correctly

3. ANS:
C

You're looking looking for elements that are to the far right of the periodic table (nonmetals) and the halogens are your only choice of nonmetals!

DIF: Easy MSC: 2008 #3 NOT: 63% answered correctly

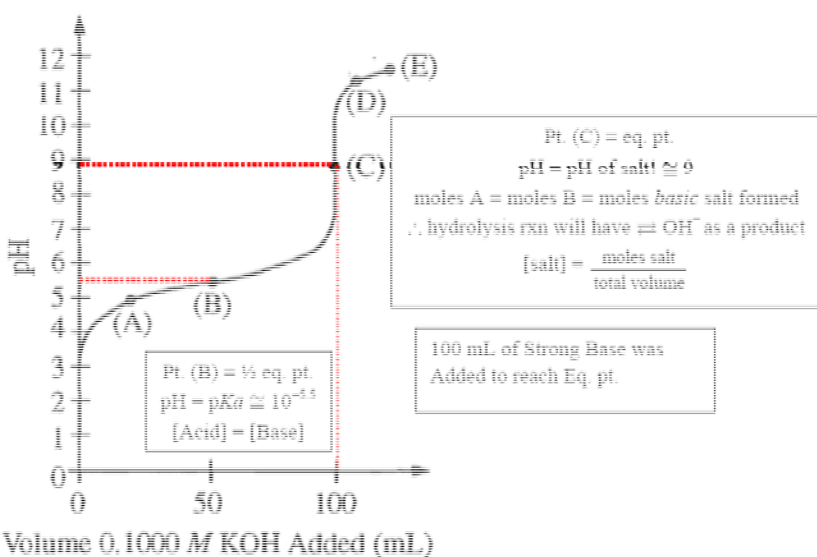
4. ANS:
C



When moles added = moles initially present you have arrived at the equivalence point which is the geometric center of the steep vertical portion of the graph.

DIF: Easy MSC: 2008 #4 NOT: 65% answered correctly

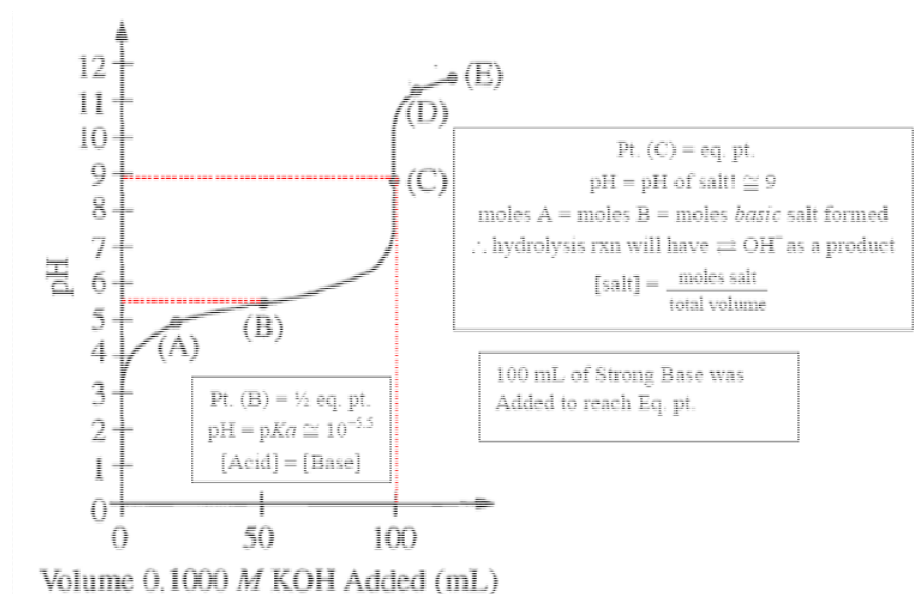
5. ANS:
E



When the equivalence point has been passed by quite a bit in the titration, the pH nears the pH of the strong base.

DIF: Easy MSC: 2008 #5 NOT: 69% answered correctly

6. ANS:
B

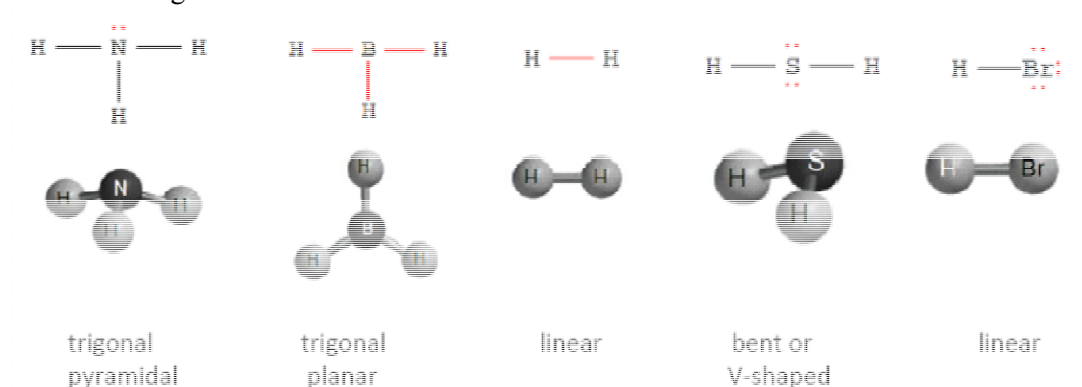


Don't forget that "conjugate base" is equivalent to "salt". Since both components share the same solution volume in the flask, and half of the weak acid has been neutralized, thus converted to salt (conjugate base if you prefer), their concentrations are equal at the $\frac{1}{2}$ equivalence point.

DIF: Hard MSC: 2008 #6 NOT: 38% answered correctly

7. ANS:
A

Draw the dang Lewis structure!



Ammonia is a classic. It obeys the octet rule, has one lone pair thus it is trigonal pyramidal as are all of its cousins such as PH_3 and NF_3 , etc. HOWEVER, BF_3 is *not* a cousin since boron is before C in the periodic table, thus allowed to violate the octet rule on the low side with only 3 pairs of e^- surrounding the central atom.

DIF: Easy MSC: 2008 #7 NOT: 68% answered correctly

8. ANS:
E

“Strong” electrolytes are like “strong” acids, both dissociate into ions quite nicely. The more mobile and charged particles in solution, the better the electrolyte. So, HBr bubbled through water makes the strong acid HBr which promptly dissociates into H^+ and Br^- ions. All of the other choices are far more molecular in nature.

DIF: Medium MSC: 2008 #8 NOT: 50% answered correctly

9. ANS:
E

“Effuse” is diffuse through a small opening. So, the heaviest molecule will effuse the slowest. HBr has the highest molecular mass, thus is slowest to effuse.

DIF: Medium MSC: 2008 #9 NOT: 62% answered correctly

10. ANS:
C

Ah, the definition of zero entropy. It’s a classic!

DIF: Medium MSC: 2008 #10 NOT: 41% answered correctly

11. ANS:
A

Did you do the NMSI crystal violet lab? If so, this was the last part. To determine the activation energy you graph $\ln k$ vs. $1/\text{Kelvin temperatures}$ and the activation energy can be calculated using $E_a = -\text{slope} \times \text{“energy R”}$ (the $8.31 \text{ J/mol} \cdot \text{K}$ one). You can also solve for the Arrhenius equation algebraically.

DIF: Hard MSC: 2008 #11 NOT: 33% answered correctly

12. ANS:
C

The second you read “spontaneous” you should think “exothermic or (–) enthalpy & (+) entropy”. Next, go directly to $\Delta G = \Delta H - T\Delta S$ and contemplate the signs of the players that give you a guaranteed *negative* value for ΔG :

$\Delta G = -\Delta H - [(+T)(+\Delta S)]$, so a negative number – a (+) term guarantees a negative “answer” for ΔG .

DIF: Medium MSC: 2008 #12 NOT: 57% answered correctly

13. ANS:
A

Water evaporates spontaneously at room temperature and requires thermal energy to do so, therefore $+\Delta H$ and since a liquid is converted into a vapor, $+\Delta S$.

DIF: Hard MSC: 2008 #13 NOT: 41% answered correctly

14. ANS:
C

Clearly combustion reactions (fire!) give off heat energy so $-\Delta H$ and since a liquid reactant is forming gaseous products $+\Delta S$.

DIF: Hard MSC: 2008 #14 NOT: 34% answered correctly

15. ANS:
B

A precipitation reaction is defined as one that mixes two aqueous solutions together as reactants and a solid product is formed (and usually filtered, then dried, etc.). So, both answer (A) & (B) form solids, but only (B) mixes two aqueous solutions together.

DIF: Easy MSC: 2008 #15 NOT: 80% answered correctly

16. ANS:
E

See those square brackets with a set of parentheses inside? Dead giveaway! Especially if there is a charge on the outside of the brackets. Beware the brackets are not always present, but if you see (NH_3) or other stuff like water or a halogen or a cyanide snuggled up to a metal where the whole scary mess has a charge...you've got a coordination complex on your hands.

DIF: Medium MSC: 2008 #16 NOT: 54% answered correctly

17. ANS:
A

element + element \rightarrow compound is the format for a synthesis, combination, composition (grown ups that can't get along, thus so many names for the same concept!) reaction.

element + element \rightarrow compound is ALSO a sure bet for a redox reaction since the oxidation state of elements in their standard state is ZERO. Thus one element is usually oxidized and the other reduced.

DIF: Medium MSC: 2008 #17 NOT: 54% answered correctly

MULTIPLE CHOICE

18. ANS: C
Qualitatively, you figure fewer moles of potassium chlorate react

$$\frac{2 \text{ mol KClO}_3}{3 \text{ mol O}_2} (1 \text{ L O}_2) \left(\frac{1 \text{ mol O}_2}{22.4 \text{ L O}_2} \right) \text{ which simplifies to } \frac{2}{3} \left(\frac{1}{22.4} \right) \text{ mol KClO}_3$$

DIF: Easy MSC: 2008 #18 NOT: 62% answered correctly

19. ANS: C

The bromide ion has 36 electrons since Br has an atomic number of 35 but gained one electron to become bromide.

Ca has an atomic number of 20, Ca^{2+} has lost two electrons, thus has $18 e^-$

K has an atomic number of 19, K^+ has lost an electron, thus has $18 e^-$

Sr has an atomic number of 38, Sr^{2+} has lost two electrons, thus has $36 e^-$ like bromide and is the correct answer.

I has an atomic number of 53, I^- has gained an electron, thus has $54 e^-$

Cl has an atomic number of 17, Cl^- has gained an electron, thus has $28 e^-$

DIF: Easy MSC: 2008 #19 NOT: 78% answered correctly

20. ANS: E

Methane obeys the octet rule, has tetrahedral geometry with 4 equivalent C–H bonds nonpolar covalent bonds having an electronegativity difference of 0.4 on the Pauling scale. Therefore, the only way methane molecules attract each other is with London dispersion forces (LDFs). The more electrons present in a nonpolar molecule the more polarizable it is, the stronger the LDFs. Also note that if the question had substituted a F for all 4 H's, the molecule would still be nonpolar (but have more electrons!), thus still only LDFs. Also note that *all* molecules exhibit LDFs as one of their intermolecular forces.

DIF: Medium MSC: 2008 #20 NOT: 46% answered correctly

21. ANS: B

“Excited” is code for freakish. So look for a weird electron configuration where one sublevel has been started before another is filled. It indicates that an electron has been “excited” to a higher sublevel or energy level like in the case of $1s^2 2s^2 2p^5 3s^2$ which would be $1s^2 2s^2 2p^6 3s^1$ in the ground state.

DIF: Easy MSC: 2008 #21 NOT: 71% answered correctly

22. ANS: C

Draw the dang Lewis structures!

Polar bonds result from electronegativity differences greater than 0.4 on the Pauling scale. But, wait! You don't have a table of E_n values, so you need to rely on periodic table positions to make your determinations.

F_2 is a nonpolar molecule with a *very* nonpolar bond (electronegativity, E_n difference of zero!). CHF_3 is a polar molecule since it obeys the octet rule, but has 4 nonequivalent bonds thus has a net dipole moment. HCl is a polar molecule with a polar bond (H and Cl are far apart on the periodic table). NH_3 is a polar molecule with a net dipole moment due to the presence of the lone pair of electrons.

CO_2 is a nonpolar molecule with polar bonds (oxygen is very E_n and C isn't, so the E_n difference is great enough to make the bond polar) which makes it the correct answer.

DIF: Medium MSC: 2008 #22 NOT: 39% answered correctly

23. ANS: B

You either did your memory work in first-year chemistry or you didn't!

Fe ions commonly have oxidation states of +2 and +3

Zn only makes a +2 ion (which should have sealed the deal for you!)

Mn ions are the most versatile with common oxidation states of +2, +3, +4, +6 and +7

DIF: Easy MSC: 2008 #23 NOT: 82% answered correctly

24. ANS: B

So, you went directly to the periodic table, right? Cs has an atomic number of 55, thus 55 protons and 55 electrons. The number of neutrons is equal to mass number – # of protons or 134 – 55 in this case which equals 79.

DIF: Easy MSC: 2008 #24 NOT: 82% answered correctly

25. ANS: A

Use your good buddy, the Ideal Gas Law to set this one up. Be sure to use the “atmosphere” R not the “energy” R. Very straight forward!

$$PV = nRT \therefore P = \frac{nRT}{V} = \frac{(1.85 \text{ mol}) \left(0.0821 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \right) (273 + 35 \text{ K})}{3.00 \text{ L}}$$

DIF: Easy MSC: 2008 #25 NOT: 87% answered correctly

26. ANS: D

The question gave us the orders for each reactant (Commence happy dance!) So, the rate law is $\text{rate} = k [\text{X}][\text{Y}]^2$ Plug and chug my darlin’s!

Use your algebraic prowess to reason that if (ignoring units)

$\text{Rate} = k [0.40][0.10]^2 = [0.40][0.01] = 0.004 = R$, then

$\text{Rate} = k[0.20][0.20]^2 = [0.20]^3 = 0.008$ which must = $2R$

DIF: Medium MSC: 2008 #26 NOT: 47% answered correctly

27. ANS: D

These are called transmutation reactions and they may look scary, but they are super easy! The masses (top numbers) and the number of protons (bottom numbers) must be equal on both sides of the arrow. Simple enough...

A) 238 vs. $232 + 4 \neq 238$ therefore, not balanced by mass

B) $249 + 15 = 264$ vs. $260 + 3(1) \neq 264$ therefore, not balanced by mass

C) $2 + 3 = 5$ vs. $4 + 2(1) \neq 5$ therefore, not balanced by mass

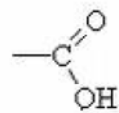
D) $238 + 1 = 239$ vs. 239, so balanced by mass. What about # protons? $92 + 0 = 92 = 92$ so we have a winner!

E) 40 vs. $40 + 0 = 40$, so balanced by mass. What about # protons? 19 vs. $20 + 1 \neq 19$, therefore not balanced by number of protons

DIF: Easy MSC: 2008 #27 NOT: 69% answered correctly

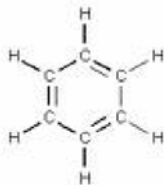
28. ANS: C

You know what I'm going to say, right? Draw the dang Lewis structures!



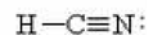
See those COOH pieces? They have a C=O and really look like this:

C₂H₆ is hexane, and contains only single bonds as to all alkanes with a general formula of C_nH_(2n+2). C₆H₆ is



benzene and looks like this:

and HCN has the cyanide ion it it which contains a triple bond and looks like this:



DIF: Easy MSC: 2008 #28 NOT: 77% answered correctly

29. ANS: B

Expect easy math and ESTIMATE! 24.5 g is really close to 25 g and 98.8 g is really close to 100 g/mol. So,

$$m = \frac{\text{moles solute}}{\text{kg solvent}} = \frac{25/100}{0.100} = \frac{0.25}{0.100} = 2.5 m$$

DIF: Medium MSC: 2008 #29 NOT: 46% answered correctly

30. ANS: B

Start with $D = \frac{m}{V}$ and contemplate the number of sig. figs. for both m and V . Easy enough for V , it was given with 4 sig. figs., but the mass is obtained as the result of a subtraction using the data given which truncates the number to the least # of decimal places. It comes out to *roughly* 20.xxx ish which is 5 sig. figs. When you divide, you go with the least # of sig. figs. so you report the final density to 4 sig. figs.

DIF: Medium MSC: 2008 #30 NOT: 54% answered correctly

31. ANS: C

Use the old "pretend it's a 100 g sample so the percents = # of grams" technique. So, estimate! Moles S =

$$\frac{30 \text{ g}}{32 \text{ g/mol}} \approx 1 \text{ mol and } F = \frac{70 \text{ g}}{19 \text{ g/mol}} \approx 4 \text{ mol which is a 1:4 S:F ratio, thus the empirical formula is SF}_4.$$

DIF: Medium MSC: 2008 #31 NOT: 65% answered correctly

32. ANS: C

For first order kinetics (which includes radioactive decay) the following method works really well. Consider that it takes 124 seconds to go from 1 to $\frac{1}{8}$ of the sample and sketch it out like this: $1.0 \rightarrow \frac{1}{2} \rightarrow \frac{1}{4} \rightarrow \frac{1}{8}$ which consumes 3 half-lives (3 arrows) which is 30ish seconds for each half-life.

DIF: Hard MSC: 2008 #32 NOT: 38% answered correctly

33. ANS: A

The “trick” to getting this one correct is to recognize that you have entered the “land of limiting reagent”! You were given two starting amounts. Determine the limiting reagent and calculate subsequent EXCESS moles from that limiting amount of moles using the mole:mole.

2 H ₂	+ O ₂	→	2 H ₂ O
mole:mole 2	1		2
# moles = 0.40	= 0.15 mol		= 0.30 mol, (twice the limiting number of moles of oxygen) not that you were asked!
IF 0.30 mol reacts with the LIMITING reactant, then 0.10 mol remain with a mass equal to (0.10 mol)(2.02 g/mol) = 0.20 g of H ₂	IF 1 = 0.15 mol, then 2 = 0.30, so this is clearly the LIMITING reactant (since you have ample H ₂ . Work from this number...		

DIF: Medium MSC: 2008 #33 NOT: 56% answered correctly

34. ANS: D

What’s the scariest looking thing in the equation? Start there...the Ca(H₂PO₄)₂ perhaps? Then you need a 3 in front of it which means 6 dihydrogen phosphates are now present and you have two plain phosphates, so try a 4 in front of the phosphoric acid. Did that do it? Yep! 12 of those pesky hydrogens on both sides...



DIF: Easy MSC: 2008 #34 NOT: 80% answered correctly

35. ANS: C

Think of these as three true-false questions which minimizes confusion!

I. True. Adding H₂(g) will shift the equilibrium to the right, favoring the products, therefore the quantity of HI will increase.

II. True. Increasing the temperature will shift the equilibrium to the right, favoring the products, therefore the quantity of HI will increase. (Since the reaction is endothermic, think of heat as a reactant which is being added to the system.)

III. False. Decreasing the pressure will have little to no effect on the equilibrium since there are 2 moles of gas on each side.

DIF: Medium MSC: 2008 #35 NOT: 56% answered correctly

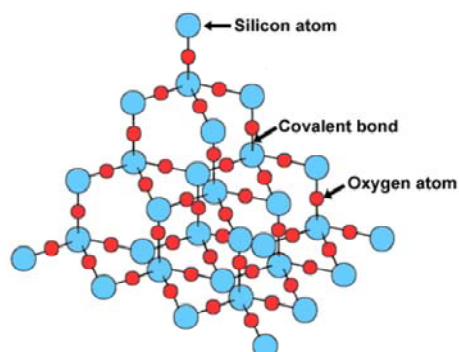
36. ANS: A

Expect easy math! The molar mass of C₂H₄ is 28 g/mol so we’re dealing with $\frac{1}{10}$ mol of C₂H₄ which contains 2 C atoms/mol, so we have $\frac{2}{10}$ of Avogadro’s number of carbon atoms which is $\left(\frac{2}{10}\right)(6 \times 10^{23}) = \frac{12}{10} = 1.2 \times 10^{23}$ C atoms.

DIF: Hard MSC: 2008 #36 NOT: 35% answered correctly

37. ANS: A

Diamond and silicon dioxide are classic examples of network covalent solids. It's important to realize that these atoms are covalently bound to each other requiring actual bonds be broken rather than overcoming IMFs.



DIF: Medium MSC: 2008 #37 NOT: 44% answered correctly

38. ANS: D

Expect easy math! You should recognize this as a dilution, so use the dilution formula $M_1 V_1 = M_2 V_2$ and solve for V_2 or realize that the “stock” is 5 times more concentrated than the diluted solution, so use 1/5 of the 500 mL desired or 100 mL diluted to 500 mL. If that doesn't occur to you...scribble out the calculation, it's a fast one.

$$V_2 = \frac{M_1 V_1}{M_2} = \frac{(2)(500)}{10} = \frac{1000}{10} = 100\text{mL}$$

DIF: Easy MSC: 2008 #38 NOT: 73% answered correctly

39. ANS: E

This one is sort of a logic problem!

$\text{SnCl}_2 + \text{CuSO}_4 \rightarrow$ (match “insides” with “outsides” like “FOIL” in Algebra I) $\rightarrow \text{CuCl}_2 + \text{SnSO}_4$, but neither is a ppt.

$\text{ZnSO}_4 + \text{SnF}_2 \rightarrow \text{SnSO}_4$ again (so not a ppt and it must be...) $+ \text{ZnF}_2$ (bingo!)

DIF: Medium MSC: 2008 #39 NOT: 58% answered correctly

40. ANS: A

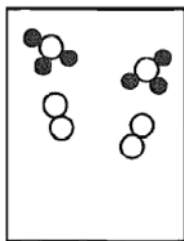
Everything is a gas except bromine, so that's your winner! But why is Br a liquid?

Bromine molecules stick to each other (because they are more attracted to each other) even though they are very, very nonpolar molecules with only London dispersion forces. It is also important to note that bromine molecules have the most electrons, and are thus more polarizable so their IMFs are stronger than the others in the lists.

DIF: Hard MSC: 2008 #40 NOT: 33% answered correctly

41. ANS: E

You have to pay attention to the initial drawing as well as respect the stoichiometry which is 3 molecules of each, so all of your hydrogen will be used up, but only one of the nitrogens (so two will be left unreacted) and you make 2 ammonias (one big white circle with 3 small black circles attached).



DIF: Medium MSC: 2008 #41 NOT: 52% answered correctly

42. ANS: E

Expect easy math!

He has a molar mass of 4 g/mol and Ne has a molar mass of 20 g/mol, therefore their ratio by mass is 5:1 respectively, therefore $P_T = P_{He} + P_{Ne} = 6 \text{ atm} = 5 \text{ atm for He} + 1 \text{ atm for Ne}$.

DIF: Hard MSC: 2008 #42 NOT: 29% answered correctly

43. ANS: C

Boiling point is defined as the temperature at which the vapor pressure of the liquid becomes equal to the atmospheric pressure on the surface of the liquid. Also note that the “normal” boiling point defines “atmospheric pressure on the surface of the liquid” to be exactly 1 atm.

DIF: Medium MSC: 2008 #43 NOT: 52% answered correctly

44. ANS: B

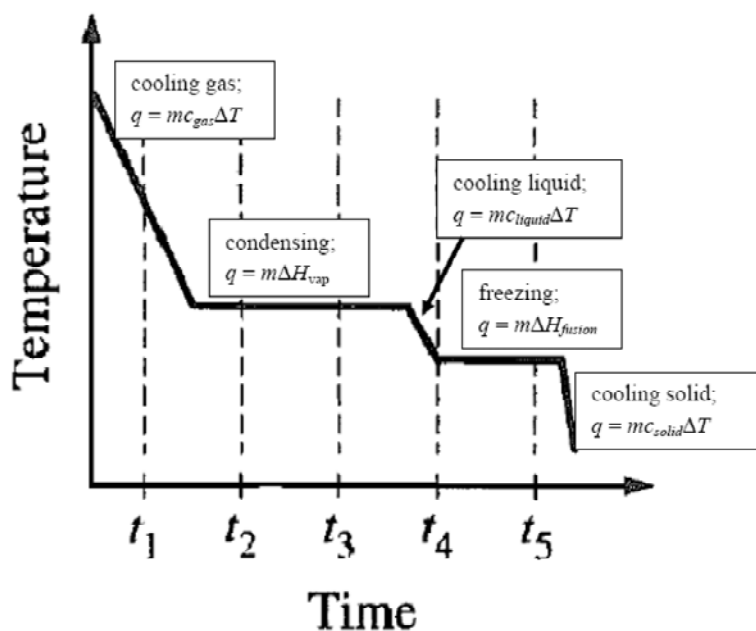
“best accounts for” is code for choosing best explanation to explain that this galvanic cell is spontaneous ($+ E^0_{\text{cell}}$ thus generates electricity). So, start with the fact that chlorine is reduced (therefore the oxidizing agent) from elemental state with an oxidation # of zero to chloride ion with an oxidation state of -1 . While iodide is oxidized (thus the reductant agent). So, Cl_2 is simply a better oxidizing agent than I_2 . Recall that for this to be a spontaneous cell, chlorine must also have a more positive reduction potential than iodine.

DIF: Medium MSC: 2008 #44 NOT: 48% answered correctly

45. ANS: D

Realize the “slants” represent temperature changes during which the entire sample is in a single phase. The “plateaus” represent a single temperature during which a phase change is taking place and the two phases are in *equilibrium*.

So, the “most liquid” will be present during t_4 since that time involves the cooling of the liquid (a “slant”) whereas t_1 represents a time when the gas is cooling. Additionally, t_2 and t_3 represent times when an equilibrium mixture of gas and liquid are present at constant temperature ($CP \rightleftharpoons BP$) and t_5 represents a time when an equilibrium mixture of liquid and solid are present at constant temperature ($FP \rightleftharpoons MP$).



DIF: Medium MSC: 2008 #45 NOT: 57% answered correctly

46. ANS: A

Expect easy math (especially when the question states “is closest to”)!

16 g of methanol is 0.5 mol and 90 g of water is 5 mol, so mole fraction of ethanol is equal to

$$\frac{\text{mole ethanol}}{\text{total moles}} = \frac{0.5}{0.5 + 5} = \frac{0.5}{5.5} = \frac{0.1}{1.1} \text{ which is really close to } 0.1 \text{ over } 1, \text{ so answer A is your best bet.}$$

DIF: Easy MSC: 2008 #46 NOT: 61% answered correctly

47. ANS: B

You always “add acid” to the water when diluting a concentrated acid (18 M in the case of H_2SO_4), especially a STRONG concentrated acid since these reactions are so exothermic due to the hydration of both hydrogen ions per molecule. If concentrated acid is added to water, the heat released can actually boil the acid right back out onto the fool that didn’t follow this safety precaution!

DIF: Hard MSC: 2008 #47 NOT: 29% answered correctly

48. ANS: B

Conjugate acid-base pairs simply differ by a proton or H^+ . Since the question is asking for the conjugate **acid**, NH_2^- is behaving as the base, thus accepting the H^+ to form NH_3 which may have thrown you off since you have embraced ammonia as the classic weak base.

DIF: Easy MSC: 2008 #48 NOT: 64% answered correctly

49. ANS: E

It pays and pays and pays to know your solubility rules! All nitrates, ammonium, IA & IIA metal salts are soluble which covers answers (A) - (D). Phosphates are generally insoluble (except for ammonium, IA & IIA metal salts).

DIF: Medium MSC: 2008 #49 NOT: 50% answered correctly

50. ANS: E

You have most likely encountered this equation several times by now since it is a NMSI lab, an example in the lecture notes, in old AP problems, etc. and just known the answer was $10 e^-$. But, here are the gory details anyway:

Red: $MnO_4^- \rightarrow Mn^{2+}$, so add 4 H_2O to the right which forces 8 H^+ be added to the left leading to a total charge of +7 and a total charge of +2 on the right, so add 5 e^- to the right.

Ox: $Br^- \rightarrow Br_2$, so double the Br^- leading to a total charge of -2 on the left and 0 on the right so add 2 e^- to the right. This forces you to multiply the 2 by 5 and the 5 by 2 to yield what you see above the question once you add the two half-reactions together and cross off the $10 e^-$ present on each side.

DIF: Hard MSC: 2008 #50 NOT: 34% answered correctly

51. ANS: C

The kinetic molecular theory states that gases behave most ideally at high temperatures (since they have enough KE to avoid being attracted to each other and condensing) and low pressures (since they remain far enough apart to avoid being attracted to each other). So, shop for the highest T which are answers (C) - (E) coupled with the lowest P which is answer (C).

DIF: Hard MSC: 2008 #51 NOT: 37% answered correctly

52. ANS: C

You are searching for anything that can expand or contract with changes of temperature which means in this list of answers, you seek something that is not a mass-mass relationship!

$$\text{mass percent} = \frac{\text{grams of part}}{\text{total grams of sample}} \times 100\%$$

$$\chi = \frac{\text{moles of part}}{\text{total moles}} \times 100\%$$

$$M = \frac{\text{moles of solute}}{\text{liters of solution (which can expand or contract, thus temperature dependent!)}}$$

$$m = \frac{\text{moles of solute}}{\text{kg of solvent}} \times 100\%$$

$$\text{ppm} = \frac{\text{grams of part}}{\text{total grams of sample}} \times 10^6$$

DIF: Medium MSC: 2008 #52 NOT: 40% answered correctly

53. ANS: D

Since $m = \frac{\text{mol solute}}{\text{kg solvent}}$ and $M = \frac{\text{mol solute}}{\text{L of sol'n}}$ so, the simplest way to do that is to measure the volume of the solution in liters.

DIF: Medium MSC: 2008 #53 NOT: 64% answered correctly

54. ANS: D

Enter Raoult's law stage left. Expect easy math and be ready to estimate!

$$P_{\text{sol'n}} = \chi_{\text{solvent}} P_{\text{solvent}}^0 = \left(\frac{9 \text{ mol H}_2\text{O}}{10 \text{ total moles}} \right) (25.0 \text{ mm Hg}) = (0.9)(25) \therefore \text{a bit less than 2.5 and 22.5 to be exact}$$

DIF: Hard MSC: 2008 #54 NOT: 21% answered correctly

55. ANS: E

Expect easy math! $K = \frac{[Z]^3}{[X]^2[Y]} = \frac{[4]^3}{[2]^2[0.5]} = \frac{64}{2} = 32$

DIF: Medium MSC: 2008 #55 NOT: 69% answered correctly

56. ANS: A

These gases are all super duper nonpolar therefore those with the most electrons are most polarizable, thus have the strongest LDFs and the converse is also true. So, pick puny little hydrogen molecules with only 2 itty bitty electrons.

DIF: Medium MSC: 2008 #56 NOT: 41% answered correctly

57. ANS: A

Ask yourself how many sites of electron density are around each carbon atom. The answer is 2 (one single bond and one triple bond, each is a site of electron density), thus the hybridization is sp (think 2 sites = 2 letters and start with s , then add p 's until you run out and go to d 's if you must). That means the bond angle is 180° should they have asked.

DIF: Hard MSC: 2008 #57 NOT: 36% answered correctly

58. ANS: D

Expect easy math! There are several ways of working this through, do what works for *you*.

$$M = \frac{\text{mol solute}}{\text{L of sol'n}} = \frac{\frac{\text{grams}}{\text{molar mass}} \left(\frac{0.360 \text{ g}}{180} \right)}{0.200} = \frac{0.002}{0.200} = \frac{0.001}{0.100} = \frac{10^{-3}}{10^{-1}} = 10^{-2} = 0.0100 M$$

DIF: Hard MSC: 2008 #58 NOT: 33% answered correctly

59. ANS: B

Focus on the balanced equation to get the equilibrium expression, then the diagram to get the “concentrations”.

$K = \frac{[\text{N}_2\text{O}_4]}{[\text{NO}_2]^2}$, so figure out the initial “concentrations”: 3 funky white blobs = N_2O_4 and 6 black dots = NO_2 , so

$$K = \frac{[3]}{[6]^2} = \frac{3}{36} \text{ which is less than 1}$$

DIF: Hard MSC: 2008 #59 NOT: 32% answered correctly

60. ANS: B

When you wish to dissolve a ppt (clearly water won’t work as the solvent, else it wouldn’t be a precipitate, huh?) you try either an acid or a base as the solvent. When you use “excess ammonia” you are headed toward making a complex ion (which will be soluble) *especially* if a metal is present.

$\text{Ni}^{2+} + \text{NH}_3 \rightarrow [\text{Ni}(\text{NH}_3)_4]^{2+}$ or tetra ammine nickel(II) ion is formed. Other coordination numbers are possible, but doubling the charge of the metal and using it as the coordination number (subscript on the ligand--in this case, NH_3 which is a neutral ligand) will get you a valid formula for the complex.

DIF: Hard MSC: 2008 #60 NOT: 33% answered correctly

61. ANS: D

Never mind the structure, if it smells (good or bad) it is usually an ester! Most of our artificial aromas are esters. Back to the structures...

- an alcohol has an $-\text{OH}$ functional group attached to a hydrocarbon
- an amine has a $-\text{NH}_2$ functional group attached to a hydrocarbon (if you add a carboxylic acid functional group as well you may have an amino acid in your midst)
- a carboxylic acid has a $-\text{COOH}$ group which is a carbon doubly bound to an oxygen and singly bound to an $-\text{OH}$ group that contains the “ H^+ ” that will be “donated”, hence the acid part of the name

• an ester has an $-\text{O}-\text{C}(=\text{O})-$ functional group

• a ketone has a $-\text{C}(=\text{O})-$ functional group that is at the end of a hydrocarbon

DIF: Hard MSC: 2008 #61 NOT: 32% answered correctly

62. ANS: B

If you want 2 decimal places on a volume measurement in mL, it is going to be an expensive device! That eliminates the last 3 choices (since we let you lot use them all the time) and the first choice is too small. Go with the 25 mL pipet (at a cost of about \$15 or more).

DIF: Hard MSC: 2008 #62 NOT: 32% answered correctly

63. ANS: B

F and O lie next to each other in the periodic table, F has 9 p^+ and O has 8 p^+ . So, F has a higher effective nuclear charge than O. The two ions are isoelectronic, each having 10 electrons, so it makes sense that 9 protons would exert a stronger attractive force on the 10 electrons pulling them closer to the nucleus than 8 protons can, thus F^- is the smaller ion.

DIF: Hard MSC: 2008 #63 NOT: 38% answered correctly

64. ANS: D

A "pH greater than 7.0" is code for "basic or alkaline". You are now in search of a base or a basic salt. So, acetic acid, $HC_2H_3O_2$, and iodic acid, HI are out right away! That leaves 3 salts. For each ask yourself which acid reacted with which base to form each salt and then is that acid or base strong or weak. Strong wins and drives the pH of the salt in solution.

KBr--KOH (strong) + HBr (strong), therefore no victor, thus a neutral salt with a pH = 7.0

NH_4Cl -- NH_4OH (weak) + HCl (strong), therefore acidic salt with a pH < 7.0

NaF--NaOH (strong) + HF (weak), therefore basic salt with a pH > 7.0

DIF: Hard MSC: 2008 #64 NOT: 33% answered correctly

65. ANS: C

This question refers to the fact that you must equilibrate the pressure inside and outside of the tube if you are to *assume* the pressure inside the tube is equal to the barometric reading or atmospheric pressure (772 torr in this case). That requires moving the gas-collection tube (eudiometer) up or down until the water level is the same outside the tube as inside the tube. Since the diagram shows the water level inside the tube is higher, the tube must be moved downward to equilibrate the pressure.

DIF: Medium MSC: 2008 #65 NOT: 43% answered correctly

66. ANS: E

Think of these as 3 T/F questions. In this case they are all true!

I. Frequency of collisions of reactant particles--TRUE--accomplished by increasing the temperature (heat 'em up, speed 'em up) or increasing the concentration (making it more crowded in the reaction vessel).

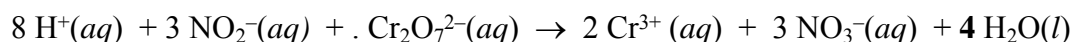
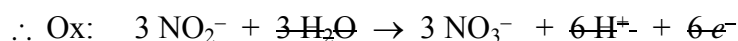
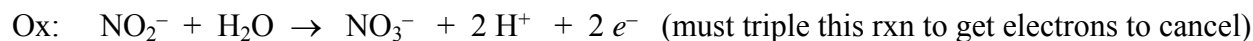
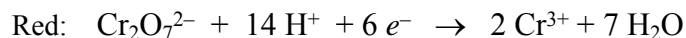
II. Kinetic energy of collisions of reactant particles--TRUE--T is the average KE of the molecules so we're back to heat 'em up, speed 'em up.

III. Orientation of reactant particles during collisions--TRUE--this increases the # of *effective* collisions which speeds up the reaction--that's *how* a catalyst speeds up a reaction, by providing an alternate pathway that often involves orienting the molecules in positions that lead to more effective collisions.

DIF: Medium MSC: 2008 #66 NOT: 52% answered correctly

67. ANS: B

This question is a time bandit since its redox. Not hard, just a time bandit! How did I know it was redox? See that H^+ on one side with H_2O on the other? It's a dead give away! Not to mention the presence of the dichromate ion (always be on the lookout for permanganate ion as well).



DIF: Hard MSC: 2008 #67 NOT: 20% answered correctly

68. ANS: B

Expect easy math!

We're diluting a strong base by cutting its molarity in half to 0.001 which is 1×10^{-3} , thus the $pOH = -\log[10^{-3}] = 3$, therefore the $pH = 14 - 3 = 11$

DIF: Hard MSC: 2008 #68 NOT: 24% answered correctly

69. ANS: A

I would call this an easy question, but you may call it a trick! If 2 samples are at the same temperature, their average molecular kinetic energy is the same since that's the definition of temperature! Over half the country missed this question.

DIF: Medium MSC: 2008 #69 NOT: 47% answered correctly

70. ANS: B

An amino acid consists of a carbon atom with 4 components: a hydrogen, an amine group $-NH_2$, a carboxylic acid group $-COOH$ (chant "C double bond O, single bond OH and it's that H^+ that makes it an acid) and a "R" group which can be as simple as a H or a complex ring structure.

DIF: Easy MSC: 2008 #70 NOT: 76% answered correctly

71. ANS: C

Least polar is code for smallest electronegativity difference, so look for atoms sitting next to each other in the periodic table. O & F are both highly electronegative, so their En difference is small.

DIF: Medium MSC: 2008 #71 NOT: 45% answered correctly

72. ANS: E

(A) and (B) bubble as gases are formed. (C) makes a ppt since sulfates are soluble EXCEPT calcium, strontium, barium, silver mercury and lead. (D) hydroxides are generally insoluble EXCEPT IA & IIA metals. That leaves answer (E) which is a solution of a strong acid and it's ammonium salt which is pretty boring--no bubbles, no ppt, no color change--rather ho hum.

DIF: Medium MSC: 2008 #72 NOT: 45% answered correctly

73. ANS: E

VP is dependent upon the average KE of the molecules, so if the temperature is the same, then the VP is the same for both samples of acetone. Again, I'd call this easy, but you may think it's a trick question.

DIF: Hard MSC: 2008 #73 NOT: 23% answered correctly

74. ANS: B

Expect easy math!

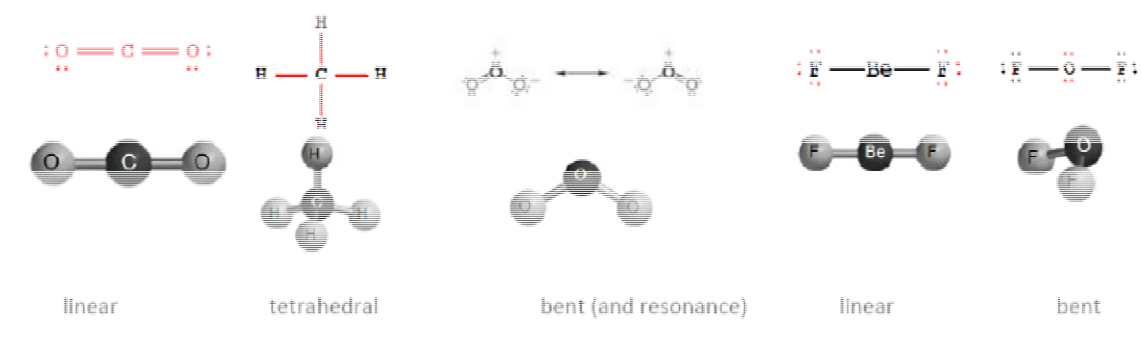
The Ni^{2+} will require 2 moles of electrons for each mole of Ni metal formed, therefore you need 2 faradays (interpret a faraday as the charge on a mole of electrons). So,

$$\# \text{coulombs} = It \therefore t = \frac{\# \text{coulombs required}}{I} = \frac{2(96,500) \text{ c}}{1 \text{ c/s}} = 193,000 \text{ s}$$

DIF: Hard MSC: 2008 # 74 NOT: 24% answered correctly

75. ANS: B

Draw the dang Lewis Structures!



DIF: Medium MSC: 2008 #75 NOT: 41% Answered Correctly



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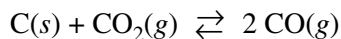
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2008 SCORING GUIDELINES

Question 1



Solid carbon and carbon dioxide gas at 1,160 K were placed in a rigid 2.00 L container, and the reaction represented above occurred. As the reaction proceeded, the total pressure in the container was monitored. When equilibrium was reached, there was still some C(s) remaining in the container. Results are recorded in the table below.

Time (hours)	Total Pressure of Gases in Container at 1,160 K (atm)
0.0	5.00
2.0	6.26
4.0	7.09
6.0	7.75
8.0	8.37
10.0	8.37

- (a) Write the expression for the equilibrium constant, K_p , for the reaction.

$K_p = \frac{(P_{\text{CO}})^2}{P_{\text{CO}_2}}$	One point is earned for the correct expression.
---	---

- (b) Calculate the number of moles of $\text{CO}_2\text{(g)}$ initially placed in the container. (Assume that the volume of the solid carbon is negligible.)

$n = \frac{PV}{RT} = \frac{(5.00 \text{ atm})(2.00 \text{ L})}{(0.0821 \frac{\text{L atm}}{\text{mol K}})(1,160 \text{ K})} = 0.105 \text{ mol}$	One point is earned for the correct setup. One point is earned for the correct answer.
--	---

- (c) For the reaction mixture at equilibrium at 1,160 K, the partial pressure of the $\text{CO}_2\text{(g)}$ is 1.63 atm. Calculate

- (i) the partial pressure of CO(g) , and

$P_{\text{CO}_2} + P_{\text{CO}} = P_{\text{total}}$ $P_{\text{CO}} = P_{\text{total}} - P_{\text{CO}_2} = 8.37 \text{ atm} - 1.63 \text{ atm} = 6.74 \text{ atm}$	One point is earned for the correct answer supported by a correct method.
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2008 SCORING GUIDELINES

Question 1 (continued)

(ii) the value of the equilibrium constant, K_p .

$K_p = \frac{(P_{\text{CO}})^2}{P_{\text{CO}_2}} = \frac{(6.74 \text{ atm})^2}{1.63 \text{ atm}} = 27.9$	<p>One point is earned for a correct setup that is consistent with part (a).</p> <p>One point is earned for the correct answer according to the setup.</p>
--	--

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

<p>The total pressure of the gases at equilibrium with a catalyst present would be equal to the total pressure of the gases without a catalyst. Although a catalyst would cause the system to reach the same equilibrium state more quickly, it would not affect the extent of the reaction, which is determined by the value of the equilibrium constant, K_p.</p>	<p>One point is earned for the correct answer with justification.</p>
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In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(s), plus CO(g) and CO₂(g), each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of CO₂(g) will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

$Q = \frac{(P_{\text{CO}})^2}{P_{\text{CO}_2}} = \frac{(2.00 \text{ atm})^2}{2.00 \text{ atm}} = 2.00 < K_p (= 27.9),$ <p>therefore P_{CO_2} will decrease as the system approaches equilibrium.</p>	<p>One point is earned for a correct calculation involving Q or ICE calculation.</p> <p>One point is earned for a correct conclusion based on the calculation.</p>
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Question 2

Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $\text{MgCl}_2 \cdot n \text{H}_2\text{O}$. The student collects the data shown in the following table.

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

- (a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

No additional mass was lost during the third heating, indicating that all the water of hydration had been driven off.	One point is earned for the correct explanation.
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- (b) Use the data above to

- (i) calculate the total number of moles of water lost when the sample was heated, and

$\text{mass of H}_2\text{O lost} = 25.825 - 23.977 = 1.848 \text{ g}$ <i>OR</i> $25.825 - 23.976 = 1.849 \text{ g}$ $1.848 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = 0.1026 \text{ mol H}_2\text{O}$	One point is earned for calculating the correct number of moles of water.
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- (ii) determine the formula of the hydrated compound.

$\text{mass of anhydrous MgCl}_2 = 23.977 - 22.347 = 1.630 \text{ g}$ $1.630 \text{ g MgCl}_2 \times \frac{1 \text{ mol MgCl}_2}{95.20 \text{ g MgCl}_2} = 0.01712 \text{ mol MgCl}_2$ $\frac{0.1026 \text{ mol H}_2\text{O}}{0.01712 \text{ mol MgCl}_2} = 5.993 \approx 6 \text{ mol H}_2\text{O per mol MgCl}_2$ $\Rightarrow \text{formula is MgCl}_2 \cdot 6\text{H}_2\text{O}$	<p>One point is earned for calculating the correct number of moles of anhydrous MgCl_2.</p> <p>One point is earned for writing the correct formula (with supporting calculations).</p>
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Question 2 (continued)

- (c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

The calculated mass (or moles) of water lost by the hydrate will be too large because the mass of the solid that was lost will be assumed to be water when it actually included some MgCl_2 as well.	One point is earned for the correct answer with justification.
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In the second experiment, a student is given 2.94 g of a mixture containing anhydrous MgCl_2 and KNO_3 . To determine the percentage by mass of MgCl_2 in the mixture, the student uses excess $\text{AgNO}_3(aq)$ to precipitate the chloride ion as $\text{AgCl}(s)$.

- (d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.

Add excess AgNO_3 . - Separate the AgCl precipitate (by filtration). - Wash the precipitate and dry the precipitate completely. - Determine the mass of AgCl by difference.	Two points are earned for <u>all three major steps</u> : filtering the mixture, drying the precipitate, and determining the mass by difference. One point is earned for any two steps.
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- (e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

- (i) The number of moles of MgCl_2 in the original mixture

$5.48 \text{ g AgCl} \times \frac{1 \text{ mol AgCl}}{143.32 \text{ g AgCl}} = 0.0382 \text{ mol AgCl}$ $0.0382 \text{ mol AgCl} \times \frac{1 \text{ mol Cl}}{1 \text{ mol AgCl}} \times \frac{1 \text{ mol MgCl}_2}{2 \text{ mol Cl}} = 0.0191 \text{ mol MgCl}_2$	One point is earned for calculating the number of moles of AgCl . One point is earned for conversion to moles of MgCl_2 .
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- (ii) The percent by mass of MgCl_2 in the original mixture

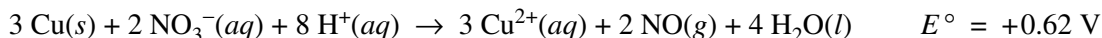
$0.0191 \text{ mol MgCl}_2 \times \frac{95.20 \text{ g MgCl}_2}{1 \text{ mol MgCl}_2} = 1.82 \text{ g MgCl}_2$ $\frac{1.82 \text{ g MgCl}_2}{2.94 \text{ g sample}} \times 100\% = 61.9\% \text{ MgCl}_2 \text{ by mass}$	One point is earned for calculating the correct percentage.
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Question 3

Answer the following questions related to chemical reactions involving nitrogen monoxide, NO(g).

The reaction between solid copper and nitric acid to form copper(II) ion, nitrogen monoxide gas, and water is represented by the following equation.



- (a) Using the information above and in the table below, calculate the standard reduction potential, E° , for the reduction of NO_3^- in acidic solution.

Half-Reaction	Standard Reduction Potential, E°
$\text{Cu}^{2+}(aq) + 2 e^- \rightarrow \text{Cu}(s)$	+0.34 V
$\text{NO}_3^-(aq) + 4 \text{ H}^+(aq) + 3 e^- \rightarrow \text{NO}(g) + 2 \text{ H}_2\text{O}(l)$?

$E_{\text{rxn}}^\circ = E_{\text{NO}_3^-}^\circ - E_{\text{Cu}^{2+}}^\circ = E_{\text{NO}_3^-}^\circ - 0.34 \text{ V} = 0.62 \text{ V}$ $\Rightarrow E_{\text{NO}_3^-}^\circ = 0.62 \text{ V} + 0.34 \text{ V} = 0.96 \text{ V}$	One point is earned for the correct calculation of the standard reduction potential.
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- (b) Calculate the value of the standard free energy change, ΔG° , for the overall reaction between solid copper and nitric acid.

$\Delta G^\circ = -n \mathcal{F} E^\circ = -(6)(96,500 \text{ C mol}^{-1})(0.62 \text{ V})$ $= -360,000 \text{ J mol}^{-1} = -360 \text{ kJ mol}^{-1}$	<p>One point is earned for the correct value of n, the number of moles of electrons.</p> <p>One point is earned for calculating the correct value of ΔG°, with correct sign and consistent units.</p>
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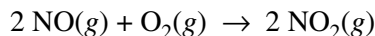
- (c) Predict whether the value of the standard entropy change, ΔS° , for the overall reaction is greater than 0, less than 0, or equal to 0. Justify your prediction.

$\Delta S^\circ > 0$. Even though there is a loss of 7 moles of ions in solution, the value of ΔS° for the overall reaction will be greater than zero because two moles of NO gas will be produced (there are no gaseous reactants).	<p>One point is earned for the correct answer with a justification that is based on the gaseous state of one of the products.</p>
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Question 3 (continued)

Nitrogen monoxide gas, a product of the reaction above, can react with oxygen to produce nitrogen dioxide gas, as represented below.



A rate study of the reaction yielded the data recorded in the table below.

Experiment	Initial Concentration of NO (mol L ⁻¹)	Initial Concentration of O ₂ (mol L ⁻¹)	Initial Rate of Formation of NO ₂ (mol L ⁻¹ s ⁻¹)
1	0.0200	0.0300	8.52×10^{-2}
2	0.0200	0.0900	2.56×10^{-1}
3	0.0600	0.0300	7.67×10^{-1}

- (d) Determine the order of the reaction with respect to each of the following reactants. Give details of your reasoning, clearly explaining or showing how you arrived at your answers.

(i) NO

Comparing experiments 1 and 3, the tripling of the initial concentration of NO while the initial concentration of oxygen remained constant at 0.0300 mol L ⁻¹ resulted in a nine-fold increase in the initial rate of formation of NO ₂ . Since $9 = 3^2$, the reaction is second order with respect to NO.	One point is earned for the correct answer with justification.
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(ii) O₂

Comparing experiments 1 and 2, the tripling of the initial concentration of O ₂ while the initial concentration of NO remained constant at 0.0200 mol L ⁻¹ resulted in a tripling in the initial rate of formation of NO ₂ . Since $3 = 3^1$, the reaction is first order with respect to O ₂ .	One point is earned for the correct answer with justification.
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- (e) Write the expression for the rate law for the reaction as determined from the experimental data.

rate = $k[\text{NO}]^2[\text{O}_2]$	One point is earned for the correct expression for the rate law.
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Question 3 (continued)

- (f) Determine the value of the rate constant for the reaction, clearly indicating the units.

<p>Because the coefficient for NO₂ in the balanced equation is 2, the rate of the reaction is defined as $\frac{1}{2}$ the rate of the appearance of NO₂.</p> <p>From part (e) above, $k = \frac{\text{reaction rate}}{[\text{NO}]^2[\text{O}_2]}$</p> $= \frac{\left(\frac{1}{2}\right)(\text{rate of formation of NO}_2)}{[\text{NO}]^2[\text{O}_2]}$ <p>Substituting data from experiment 1,</p> $k = \frac{\left(\frac{1}{2}\right)(8.52 \times 10^{-2} \text{ mol L}^{-1} \text{ s}^{-1})}{(0.0200 \text{ mol L}^{-1})^2(0.0300 \text{ mol L}^{-1})}$ $= 3.55 \times 10^3 \text{ L}^2 \text{ mol}^{-2} \text{ s}^{-1}$	<p>One point is earned for calculating the correct value of the rate constant.</p> <p>One point is earned for including the correct units.</p>
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Note: a rate constant value of $7.10 \times 10^3 \text{ L}^2 \text{ mol}^{-2} \text{ s}^{-1}$ earns the point if the rate of reaction is assumed to be the same as the rate of formation of NO₂.

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Question 4

- (a) Aqueous sodium hydroxide is added to a saturated solution of aluminum hydroxide, forming a complex ion.

<p>(i) Balanced equation:</p> $\text{Al(OH)}_3 + \text{OH}^- \rightarrow [\text{Al(OH)}_4]^-$ $\text{Al(OH)}_3 + 3 \text{OH}^- \rightarrow [\text{Al(OH)}_6]^{3-}$ $\text{Al}^{3+} + 4 \text{OH}^- \rightarrow [\text{Al(OH)}_4]^-$ $\text{Al}^{3+} + 6 \text{OH}^- \rightarrow [\text{Al(OH)}_6]^{3-}$	<p>One point is earned for the correct reactants.</p> <p>Two points are earned for a correct product.</p> <p>One point is earned for balancing the equation.</p>
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- (ii) If the resulting mixture is acidified, would the concentration of the complex ion increase, decrease, or remain the same? Explain.

<p>The $[\text{Al(OH)}_4]^-$ will decrease because ...</p> <p>(If equilibrium exists), the H^+ added would react with the OH^- in solution, reducing the $[\text{OH}^-]$ and shifting the equilibrium toward the reactants, thus reducing the concentration of the complex ion.</p> <p><i>OR</i></p> <p>(If the reaction has gone to completion), the H^+ added would react with the $[\text{Al(OH)}_4]^-$, thus reducing the concentration.</p> $[\text{Al(OH)}_4]^- + \text{H}^+ \rightarrow \text{Al(OH)}_3 + \text{H}_2\text{O}$	<p>One point is earned for a correct answer with an explanation.</p>
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Question 4 (continued)

(b) Hydrogen chloride gas is oxidized by oxygen gas.

<p>(i) Balanced equation</p> $4 \text{HCl} + \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + 2 \text{Cl}_2$ <p>Some other acceptable equations and products:</p> $4 \text{HCl} + 3 \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + 4 \text{ClO}$ $4 \text{HCl} + 5 \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + 4 \text{ClO}_2$ $4 \text{HCl} + 7 \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + 4 \text{ClO}_3$ $2 \text{HCl} + \text{O}_2 \rightarrow 2 \text{HClO}$ $\text{HCl} + \text{O}_2 \rightarrow \text{HClO}_2$ $2 \text{HCl} + 3 \text{O}_2 \rightarrow 2 \text{HClO}_3$ $\text{HCl} + 2 \text{O}_2 \rightarrow \text{HClO}_4$	<p>One point is earned for the correct reactants.</p> <p>Two points are earned for the correct products.</p> <p>One point is earned for balancing the equation.</p>
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(ii) If three moles of hydrogen chloride gas and three moles of oxygen gas react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

<p>O_2 would be in excess because of the stoichiometry of the reaction; 4 moles of HCl are consumed for 1 mole of O_2. (It takes only 0.75 mole of O_2 to react with 3 moles of HCl, leaving an excess of 2.25 moles of O_2.)</p> <p>For other acceptable equations and products, the excess reactant must be based on the stoichiometry of the reaction given by the student.</p>	<p>One point is earned for a correct answer that is based on the balanced chemical equation and that has an appropriate justification.</p>
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Question 4 (continued)

(c) Solid potassium oxide is added to water.

<p>(i) Balanced equation:</p> $\text{K}_2\text{O} + \text{H}_2\text{O} \rightarrow 2 \text{K}^+ + 2 \text{OH}^-$	<p>One point is earned for the correct reactants.</p> <p>Two points are earned for the correct products.</p> <p>One point is earned for balancing the equation.</p>
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(ii) If a few drops of phenolphthalein are added to the resulting solution, what would be observed? Explain.

<p>The solution would turn pink because the production of OH^- makes the solution basic. In basic solutions, phenolphthalein turns pink.</p>	<p>One point is earned for the correct answer with an explanation.</p>
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Question 5

Using principles of atomic and molecular structure and the information in the table below, answer the following questions about atomic fluorine, oxygen, and xenon, as well as some of their compounds.

Atom	First Ionization Energy (kJ mol ⁻¹)
F	1,681.0
O	1,313.9
Xe	?

- (a) Write the equation for the ionization of atomic fluorine that requires 1,681.0 kJ mol⁻¹.

$\text{F}(g) \rightarrow \text{F}^+(g) + e^-$	One point is earned for the correct equation. (Phase designations are not required.)
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- (b) Account for the fact that the first ionization energy of atomic fluorine is greater than that of atomic oxygen. (You must discuss both atoms in your response.)

In both cases the electron removed is from the same energy level ($2p$), but fluorine has a greater effective nuclear charge due to one more proton in its nucleus (the electrons are held more tightly and thus take more energy to remove).	One point is earned for recognizing that the effective nuclear charge of F is greater than that of O.
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- (c) Predict whether the first ionization energy of atomic xenon is greater than, less than, or equal to the first ionization energy of atomic fluorine. Justify your prediction.

The first ionization energy of Xe should be less than the first ionization energy of F. To ionize the F atom, an electron is removed from a $2p$ orbital. To ionize the Xe atom, an electron must be removed from a $5p$ orbital. The $5p$ is a higher energy level and is farther from the nucleus than $2p$, hence it takes less energy to remove an electron from Xe.	One point is earned for a prediction based on size and/or energy level.
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Question 5 (continued)

- (d) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4 . In the boxes provided, draw the complete Lewis electron-dot diagram for each of the molecules represented below.

XeO_3	XeF_4	
		<p>One point is earned for each correct Lewis electron-dot diagram.</p> <p>Omission of lone pairs of electrons on the O or F atoms results in a one-time, 1-point deduction.</p>

- (e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:

- (i) The geometric shape of the XeO_3 molecule

Trigonal pyramidal	One point is earned for a shape that is consistent with the Lewis electron-dot diagram.
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- (ii) The hybridization of the valence orbitals of xenon in XeF_4

sp^3d^2	One point is earned for the hybridization consistent with the Lewis electron-dot diagram.
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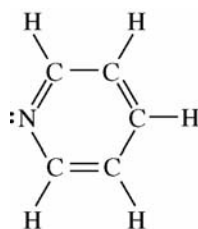
- (f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

<p>The XeO_3 molecule would be polar because it contains three polar $\text{Xe}-\text{O}$ bonds that are asymmetrically arranged around the central Xe atom (i.e., the bond dipoles do not cancel but add to a net molecular dipole with the Xe atom at the positive end).</p>	<p>One point is earned for the answer that is consistent with the shape indicated in part (e)(i).</p> <p>One point is earned for an explanation correctly related to the shape in part (e)(i).</p>
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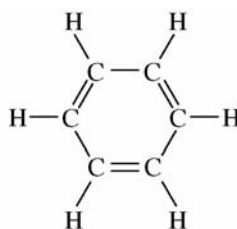
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Question 6

- (a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water, whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.



Pyridine



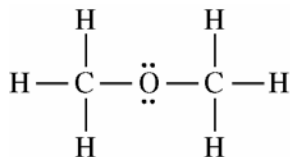
Benzene

Pyridine is polar (and capable of forming hydrogen bonds with water), while the nonpolar benzene is not capable of forming hydrogen bonds. Pyridine will dissolve in water because of the strong hydrogen bonds (or dipole-dipole intermolecular interactions) that exist between the lone pair of electrons on pyridine's nitrogen atom and the solvent water molecules. No such strong intermolecular interaction can exist between benzene and water, so benzene is insoluble in water.

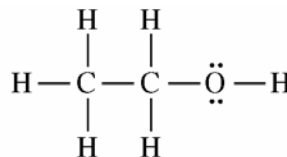
One point is earned for identifying a relevant structural difference between pyridine and benzene.

One point is earned for indicating that pyridine is soluble in water because pyridine can form strong dipole-dipole interactions (or hydrogen bonds) with water, while benzene cannot.

- (b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.



Dimethyl Ether



Ethanol

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Question 6 (continued)

<p>The intermolecular forces of attraction among molecules of dimethyl ether consist of London (dispersion) forces and weak dipole-dipole interactions. In addition to London forces and dipole-dipole interactions that are comparable in strength to those in dimethyl ether, ethanol can form hydrogen bonds between the H of one molecule and the O of a nearby ethanol molecule. Hydrogen bonds are particularly strong intermolecular forces, so they require more energy to overcome during the boiling process. As a result, a higher temperature is needed to boil ethanol than is needed to boil dimethyl ether.</p>	<p>One point is earned for recognizing that ethanol molecules can form intermolecular hydrogen bonds, whereas dimethyl ether molecules do not form intermolecular hydrogen bonds.</p> <p>One point is earned for recognizing that, compared to the energy required to overcome the weaker intermolecular forces in liquid dimethyl ether, more energy is required to overcome the stronger hydrogen bonds in liquid ethanol, leading to a higher boiling point.</p>
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- (c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss both of the substances in your answer.

<p>In the solid phase, SO_2 consists of discrete molecules with dipole-dipole and London (dispersion) forces among the molecules. These forces are relatively weak and are easily overcome at a relatively low temperature, consistent with the low melting point of SO_2.</p> <p>In solid SiO_2, a network of Si and O atoms, linked by strong covalent bonds, exists. These covalent bonds are much stronger than typical intermolecular interactions, so very high temperatures are needed to overcome the covalent bonds in SiO_2. This is consistent with the very high melting point for SiO_2.</p>	<p>One point is earned for recognizing that SO_2 is a molecular solid with only weak dipole-dipole and London forces among SO_2 molecules.</p> <p>One point is earned for recognizing that SiO_2 is a covalent network solid, and that strong covalent bonds must be broken for SiO_2 to melt.</p>
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Question 6 (continued)

- (d) The normal boiling point of $\text{Cl}_2(l)$ (238 K) is higher than the normal boiling point of $\text{HCl}(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

The intermolecular forces in liquid Cl_2 are London (dispersion) forces, whereas the intermolecular forces in liquid HCl consist of London forces and dipole-dipole interactions. Since the boiling point of Cl_2 is higher than the boiling point of HCl , the London forces among Cl_2 molecules must be greater than the London and dipole-dipole forces among HCl molecules. The greater strength of the London forces between Cl_2 molecules occurs because Cl_2 has more electrons than HCl , and the strength of the London interaction is proportional to the total number of electrons.

One point is earned for recognizing that the London forces among Cl_2 molecules must be larger than the intermolecular forces (London and dipole-dipole) among HCl molecules.

One point is earned for recognizing that the strength of the London forces among molecules is proportional to the total number of electrons in each molecule.



Student Performance Q&A:

2008 AP[®] Chemistry Free-Response Questions

The following comments on the 2008 free-response questions for AP[®] Chemistry were compiled by the Chief Reader, Eleanor Siebert of Mount St. Mary's College in Los Angeles, California. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student performance in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question 1

What was the intent of this question?

This question was designed to probe student understanding of gases and gaseous equilibria. Part (a) required students to write the expression for K_p . In part (b) students were asked to determine the number of moles of $\text{CO}_2(\text{g})$ given the volume, pressure, and temperature. This determination required the use of the ideal gas law. In part (c)(i) students had to select the correct data from the table and use Dalton's law of partial pressures to determine the pressure of $\text{CO}(\text{g})$ at equilibrium. In part (c)(ii) students were asked to determine the value of K_p using equilibrium pressures. In part (d) they had to explain the effect of a catalyst on the total pressure of gases at equilibrium. In part (e) students were given a new set of initial conditions and asked to determine the direction the reaction would proceed to reach equilibrium.

How well did students perform on this question?

Generally, students performed in the middle range on this question. The mean score was 4.17 out of 9 possible points. Students often earned points in parts (b), (c)(ii), and (d). The most frequently earned point was in part (d), while the most frequently missed points were for part (e). Students often exhibited a better conceptual knowledge of gases than mathematical skills when using data.

What were common student errors or omissions?

Common student errors in part (a) included failing to express K_p in terms of pressure (typically substituting concentration) or copying the expression $K_p = K_c(RT)^{\Delta n}$ from the "Advanced Placement Chemistry Equations and Constants" sheet in the exam booklet and attempting to use it.

In parts (b) and (c) students often failed to recognize the significance of initial versus equilibrium pressures for their calculations. Also, students often made algebraic errors. In part (c)(i) students were frequently confused about when to use the stoichiometric relationship between the gases given in the reaction.

In part (e) students often did not use a calculation in the justification even though they were asked to do so; they also frequently used stoichiometric reasoning and/or Le Chatelier's principle instead of comparing the reaction quotient, Q , to K_p .

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

- Teachers should ask students to write equilibrium expressions in their classroom assessments. They should also ask students to distinguish between a K_c expression and a K_p expression. The use of simulated lab data as a follow-up to labs may help students better distinguish between initial values of measurements and equilibrium values.
- Teachers should work with students to help them develop a qualitative and quantitative ability to justify predictions.
- Finally, teachers should stress to their students that they should read all of the parts of a question thoroughly and answer the question as it was written.

Question 2

What was the intent of this question?

This question assessed student knowledge and skills relating to gravimetric analysis, which is included in several of the laboratory experiments recommended in the *AP Chemistry Course Description*. In parts (a) through (c) students were asked to analyze and interpret a data table. They had to explain how they correctly determined that all the water of hydration had been driven off from a sample of a hydrate; calculate an appropriate formula for the hydrate; and determine the effect of an error in laboratory procedure on the calculation of the mass of water released upon heating. Parts (d) and (e) required students to describe a quantitative laboratory procedure to determine the mass of a precipitate from a mixture and then calculate the number of moles and percent by mass of a component of the mixture.

How well did students perform on this question?

Overall, students did reasonably well when answering this question. The mean score was 4.15 out of 10 possible points, and the distribution of scores was relatively even.

Students were generally successful on parts (a) and (b)(i), and responses that earned 1 to 2 points usually garnered them here. Part (b)(ii) proved a bit more challenging, as students frequently used an incorrect mass to calculate the number of moles of water of hydration and determine the formula.

In part (c) students usually recognized that the laboratory procedure error described would result in a calculation of too large a mass of water; however, many had difficulty providing an appropriate justification and consequently failed to earn the point.

In part (d) most students described a quantitative laboratory procedure for the isolation of a precipitate, but many did not elaborate sufficiently to earn full credit. While most students recognized filtration as the method of choice, they often did not include the necessary step of drying the precipitate prior to weighing, nor did they explain the need to determine the mass of the precipitate by difference. A significant proportion of students misinterpreted the intent of the question; these students attempted a mathematical explanation of the steps necessary to calculate the mass of AgCl from the data.

In part (e)(i) students were generally successful with the calculation of the moles of MgCl_2 ; however, many used an incorrect value for the total mass of the sample in part (e)(ii) and so did not earn the final point.

What were common student errors or omissions?

- (a) Students most frequently answered this part correctly. Common errors were:
- A description or restatement of the data provided, without explanation
 - An unclear explanation of the term “constant mass”
 - A description of the data as having high accuracy and/or precision
- (b)(i) Students frequently answered this part correctly as well. Common errors were:
- Calculating an incorrect mass of water from the data (students often reversed the water and MgCl_2)
 - Subtraction errors
 - Failing to round the final answer appropriately and reporting an answer with the wrong number of significant figures
- (b)(ii) Two points were available for this question, and students often earned one point for applying a mole ratio to end up with a hydrated formula. Common errors were:
- Using an incorrect mass to determine the moles of MgCl_2
 - Failing to recognize that a mole ratio was required and applying the number of moles of water to the formula
 - Misunderstanding the meaning of the term “formula” (some students tried to provide a balanced equation for a reaction between H_2O and MgCl_2 instead)
- (c) Many students were able to correctly identify the effect of the error but unable to supply an appropriate justification. Common errors were:
- Confusion between the terms “hydrate” and “water”
 - Not understanding that the hydrate was a solid and that water would not also “splash out”
- (d) This was the most difficult part of the question for students. Common errors were:
- Omitting at least one of the required three steps (filtering, drying, or weighing the precipitate by difference)
 - Stating only the need to weigh or mass the precipitate
 - Not describing the steps in sufficient detail
 - Referencing the hydrate procedure from the first part of the question

- (e)(i) Many students earned at least one point in this part. Common errors were:
- Miscalculation of the molar mass of AgCl
 - Failure to recognize the 1:2 stoichiometric ratio between MgCl_2 and AgCl
 - Not answering the question and calculating the mass of MgCl_2
 - Using an incorrect mass of the sample from another part of the question
 - Failing to round the final answer appropriately and reporting an answer with an incorrect number of significant figures
- (e)(ii) Many students answered this question correctly. Common errors were:
- Using an incorrect value for the total mass of the sample
 - Trying to calculate a percent error rather than the percent by mass
 - Calculating the mass of MgCl_2 but not using it to calculate the percent by mass
 - Failing to round the final answer appropriately and reporting an answer with an incorrect number of significant figures

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

- Have students perform the recommended laboratory experiments.
- Provide opportunities for students to engage in guided-inquiry experiments. Students need to practice the analysis of data collected in tabular form and also be able to recognize when data are valid.
- Give students laboratory experiences in which technique is important, as was the case in part (d). Students rarely mentioned that the precipitate should be washed and rinsed to remove the other soluble salts.
- Remind students that significant figures are important in calculations, and review the rules for addition and subtraction.
- Deemphasize the use of algorithms for numerical calculations. Students are often able to solve gravimetric stoichiometry problems but are unaware of the intermediate values calculated.

Question 3

What was the intent of this question?

This question tested a diverse set of student skills. Parts (a) and (b) were intended to assess the ability of students to understand the relationship among standard reduction potentials of half-reactions and the cell potential, and the relationship between the cell potential and the change in Gibbs free energy of the reaction. Part (c) assessed students' ability to relate the change in entropy of the reaction to the phases of reactants and products given in the balanced equation. Parts (d), (e), and (f) required students to answer questions related to the kinetics of a different reaction; calculate reaction orders from experimental data; write a rate law that was consistent with the orders; and determine a rate constant. Those parts of the question were intended to assess the students' understanding of kinetics and the meaning of reaction orders, and their ability to write and interpret a rate law.

How well did students perform on this question?

Because this question assessed a broad range of skills, the range of student performance was also quite broad. The mean score was 3.65 out of 9 possible points. Surprisingly, the modal score was 0, with 18 percent of the responses failing to earn any points and another 6 percent of papers left completely blank. Those students who were able to earn points on the question performed fairly well, and the distribution of scores from 1 through 9 was relatively even. Many students earned all of the points available on parts (a) through (c) but earned no points on parts (d) through (f), or vice versa; this suggests that one or more of the topics had likely been omitted or covered superficially in the students' courses.

What were common student errors or omissions?

In part (a) the most common answer was obtained by simply subtracting the values of E° given, obtaining +0.28 V rather than the correct +0.96 V. Because the unit (V) was provided in the values, responses that omitted the unit still earned the point.

In part (b) common errors included:

- Identifying an incorrect number of electrons transferred in the reaction, with common errors of $n = 5$ (sum of electrons in each half-reaction) and $n = 22$ (sum of coefficients in balanced equation)
- Using E° for one of the half-reactions (answer carried down from part [a] rather than the cell potential given)
- Giving incorrect or inconsistent units or omitting units altogether
- Omitting the algebraic sign of ΔG°

In part (c) many students attempted to determine the $+/-$ sign of ΔS° from the relationship $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ and then use the value of ΔG° obtained in part (b). A small fraction of responses determined the incorrect sign of ΔS° by considering the total number of moles of products versus reactants and failing to look carefully at the phases.

In part (d) many students performed well, but common errors included:

- Incorrect algebra (e.g., $3^n = 9 \Rightarrow n = 3$)
- Failure to provide justification

In part (e) common errors included:

- Omission of rate constant
- Exponents that were inconsistent with values obtained in part (d)
- Writing an equilibrium expression rather than a rate law

In part (f) those students who wrote a well-formed rate law in part (e) also did well here. The most common errors included:

- Failing to include units or including incorrect units (e.g., $M s^{-1}$)
- Substituting inconsistent value from the experimental data
- Poor algebra and an inability to use scientific notation
- Confusion between the rate of reaction and the rate constant, k

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

- Student performance on tasks like part (a) might be improved by encouraging students to write an equation that relates the cell potential to those of the half-reactions.
- Emphasize “ballpark” values and the physical meaning of numerical quantities (e.g., students should recognize that $-360,000 \text{ kJ mol}^{-1}$ is an absurdly large value for the ΔG° of a chemical reaction).
- Give students practice writing and interpreting rate laws, with particular emphasis on units of reaction rates, rate constants, rates of formation, and concentrations.
- Emphasize the precise use of symbols and notation (e.g., mol versus m versus M , k versus K , parentheses versus brackets, and the appropriate use of superscripts and subscripts).

Question 4

What was the intent of this question?

This question was intended to assess students’ ability to write both molecular and net-ionic equations and to recognize when each is appropriate. Various aspects of the question were intended to reinforce knowledge gleaned from the classroom and from experience in the laboratory.

How well did students perform on this question?

Students displayed a wide range of knowledge and skills in their responses to this question. The mean score was 6.81 out of 15 possible points. Scores covered the range from 0 to 15, with close to a perfect bell-shaped distribution curve. The most common scores were 4, 5, and 6, and there were relatively few blank papers.

What were common student errors or omissions?

Common student errors included:

- Showing insoluble substances, or substances stated to be solid or gaseous, in ionized form
- Showing gaseous forms as if in aqueous solution
- Including spectator ions in the same form on both sides of the equation
- Not balancing equations so that coefficients are in terms of lowest whole numbers
- Not canceling reagents that appear on both sides of the equation
- Confusing the terms “colorless” and “clear” (CuSO_4 , for example, forms a clear but colored solution)
- Mistaking common formulas (e.g., writing “ HCl_2 ” rather than “ HCl ,” or “ 2Cl ” rather than “ Cl_2 ”)
- Using inexact language (e.g., “phenolphthalein will show its basic color” rather than “phenolphthalein turns pink in basic solution”)
- Reading the prompt inexactly (e.g., not writing the formula of a complex ion when directed to do so)
- Balancing by stoichiometry of atoms but not by charge
- Omitting an explanation or justification following an assertion in parts (a)(ii), (b)(ii), and (c)(ii)
- Writing more than one answer in the provided answer box

- Placing charges within formulas (e.g., “ H^+Cl^- ” rather than “HCl”)
- Adding inappropriate products just to “balance” the equation
- Adding and omitting randomly the charges on species in the written reaction

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

- Give students practice with writing net-ionic equations. Emphasize fundamental knowledge and skills regarding equation writing, including elemental forms and common ions, especially polyatomic anions. Student responses often showed errors in the systematic presentation of chemical species, including soluble versus insoluble salts, strong versus weak acids or bases, and gaseous versus aqueous states. Some students also had difficulty with the art of balancing equations, neglecting to conserve either mass or charge.
- Encourage students to write balanced net-ionic equations to describe their work in the laboratory. A student who has performed an acid-base titration with phenolphthalein as an indicator is unlikely to forget the characteristic pink color of the indicator as the solution becomes basic at the titration’s endpoint. Similarly, a student who has created a precipitate of $\text{Al}(\text{OH})_3$ by adding strong base drop-wise to a solution containing aluminum(III) cation is apt to remember the excitement of redissolving that precipitate by continuing to add drops of strong base to form a complex ion. A student who has oxidized $\text{HCl}(\text{g})$ with $\text{O}_2(\text{g})$ in the lab is not following safe lab practices, but that student should have been taught that HCl is not ionized in the gaseous state.
- Remind students to refer to the resources available to them during the exam, specifically the “Periodic Table of the Elements” and “Standard Reduction Potentials in Aqueous Solution at 25°C ” pages in the exam booklet, for memory prompts about the behavior of elements and common ions.
- Provide students with opportunities to practice writing about chemistry. Precise language is important. For example, many responses for part (a)(ii) were unclear as to whether the added acid reacted with the complex or the hydroxide ions from the ionized NaOH. Many descriptions of LeChâtelier shifts or limiting reactants were vague. A good observation in the lab is not “it changed color” but specifically what the color change was. It is not sufficient to say “the acid reacted with the ions.” What ions? What reaction occurred? Instead, specify why the added acid affected the concentration of the complex ion. Pronouns should have unambiguous antecedents; sentences that might have made sense if written as “the acid reacts with the base and tends to neutralize the solution” were too often seen as a statement such as “it reacts with it and tends to neutralize it.”

Question 5

What was the intent of this question?

This question was designed to assess student understanding of the structure and properties of atoms and molecules. In parts (a) through (c) students had to demonstrate their understanding of ionization energy and provide explanations for its variance among different atoms. In parts (d) through (f) students were

required to sketch Lewis electron-dot diagrams, identify molecular shape and hybridization, and predict molecular polarity.

How well did students perform on this question?

The mean score was 3.92 out of 9 possible points, with scores of 4 and 5 both being modal. This question had a wide bell-shaped distribution of scores.

What were common student errors or omissions?

In part (a) the correct chemical equation was seldom obtained. Some responses attempted to develop a mathematical equation involving the given value of the first ionization energy.

In parts (b) and (c) the explanations that were to be made on the basis of nuclear charge and atomic size instead often involved discussions of periodic trends, electron configuration, or electronegativity.

In part (d) most students drew correct Lewis electron-dot diagrams. Performance varied when students attempted to use these diagrams to reason out the shape, the central atom hybridization, and then molecular polarity.

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

- Students need to be able to discuss the factors determining the trends of atomic properties. They must also understand the difference between periodic trends and the explanation for what is responsible for such trends.
- Some students need help in distinguishing between the first-ionization energy and electron affinity.
- Students need to practice the reasoning sequence employed in understanding molecular structure: complete a Lewis electron-dot diagram, use this to determine the electron-pair orientation and thus the molecular shape, and then use the shape to find the central atom hybridization and molecular polarity. The role of symmetry in determining polarity needs to be stressed.

Question 6

What was the intent of this question?

This question explored the importance of intermolecular interactions in phase changes and dissolution. To earn full credit, a student had to identify the relevant forces involved in each process. In part (a) students had to explain that pyridine's ability to hydrogen bond with water distinguishes its aqueous solubility from that of benzene. In part (b) students had to recognize that while ethanol and dimethyl ether (structural isomers) have similar dispersion forces, the hydrogen bonding between ethanol molecules leads to a higher boiling point. Part (c) required students to contrast the melting points of a network covalent solid (in which strong covalent bonds are broken in the melting transition) and a molecular solid (in which only relatively weak intermolecular attractions must be overcome). In part (d) students had to recognize that the London/dispersion interactions between Cl_2 molecules must be greater than the total intermolecular forces between HCl molecules, and then attribute the difference to the larger number of electrons in the Cl_2 molecules.

How well did students perform on this question?

Students did poorly on this question. The mean score was only 1.86 out of 8 possible points. Both the median and modal scores were 1. Answers revealed a widespread misunderstanding concerning the differences between the interactions between molecules and the bonds that hold atoms together.

What were common student errors or omissions?

In all parts of the question, many students showed uncertainty about the distinctions between molecules and atoms, and between intermolecular forces and covalent (intramolecular) bonds. Many responses contained the ambiguous phrase “the forces holding the molecules together” or similar constructions, and it was difficult for Readers to determine whether the students intended to refer to inter- or intramolecular forces.

Part (a): Many students said that pyridine molecules “dissociated” or “came apart” when they dissolved in water, while the benzene bonds were so strong that they could not come apart. Students often attributed the solubility of pyridine to the solubility of ammonium or nitrate compounds. Appropriate discussions of the nature of the interaction between pyridine and water were rare; the adage that “like dissolves like” was used by a vast majority of the students, but it did not by itself earn credit because it was not an explanation or a discussion of the interaction between either of the solutes and water.

Part (b): The fundamental error made in a plurality (if not a majority) of the responses was that the covalent bonds within dimethyl ether and ethanol must be broken for the material to boil. A very common answer indicated that the C–C bond in ethanol was stronger than the C–O bonds in dimethyl ether, so that more energy was needed to break apart ethanol. A variation on this theme was to say that ethanol’s oxygen was easier (or harder) to remove than the (protected, less-conspicuous, or less-exposed) oxygen in the center of dimethyl ether.

Students frequently identified the (covalent) O–H bond in ethanol as a hydrogen bond, and they cited the ease of breaking the O–H bond in ethanol as the reason for the difference in boiling points (indeed, students often identified any covalent bond to hydrogen as a hydrogen bond). Students often referred to ethanol’s hydrogen bonding as “the strongest bond,” stronger than any of dimethyl ether’s covalent bonds. Dimethyl ether was almost uniformly (and incorrectly) classified as nonpolar, and many students attempted incorrect explanations of boiling point differences based on the apparent linearity of dimethyl ether or the length of the hydrocarbon chain in ethanol.

Part (c): A very common error based the difference in melting points on the covalent bond orders in Lewis electron-dot diagrams for SO_2 and SiO_2 molecules. Comparison of covalent and ionic bond strengths was another common approach. Differences in electronegativities among the three elements (S, Si, O) were frequently cited, as were their relative positions on the periodic table. The properties of elemental S, Si, and O were also repeatedly invoked.

Many responses displayed the misunderstanding that “network covalent bonds are stronger than regular covalent bonds,” rather than comparing the network covalent bond strength in SiO_2 to the strength of the intermolecular forces between SO_2 molecules.

Students often classified SiO_2 as an ionic compound, and many responses referred to Si as a transition metal.

Part (d): It was apparent that many students are fundamentally confused about the difference between intramolecular Cl–Cl and H–Cl bonds and the intermolecular interactions between Cl₂ and HCl molecules. Responses often attributed double bonds to Cl₂ (and HCl), and comparisons between the triple (or quadruple) bond in Cl₂ and the double bond in HCl were common. The Cl₂ molecule was often said to be polar, while HCl was nonpolar. Students often attributed some property (or properties) to Cl₂ because “it is diatomic.” Students often cited periodic trends or positions of H and Cl on the periodic table.

Students interchangeably identified Cl₂ and HCl as ionic, polar, or nonpolar and as having ionic bonding, covalent bonding, hydrogen bonding, dipole-dipole, ion-dipole, and dispersion forces. Any selection of these forces, in any combination or order, could be found as students tried to justify the difference in boiling points. Responses frequently tried to invoke the dissociation of HCl as a strong acid to explain its low boiling point.

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

Students have clearly been exposed to the material covered in this question. While they used the correct vocabulary, they generally used it incorrectly. The correct phrase “network covalent bonds” appeared in answers to part (c), for example, but the subsequent prose showed that students did not know what it meant. The bonds between atoms in molecules must be distinguished from the interactions that keep the molecules attracted to each other. The forces within a molecule are different from the forces between them. Phrases like “the intermolecular forces within the molecule” illuminate a major misunderstanding that must be addressed. The phrase “the forces holding molecules together” (and similar constructions) is ambiguous and should be avoided in favor of clear language, such as “forces between molecules” and “forces within molecules.”

AP Chemistry
Student Grade Distributions
AP Examinations - May 2008

Examination Grade	Chemistry	
	N	% At
5	18,505	18.4
4	17,616	17.5
3	20,071	20.0
2	14,351	14.3
1	30,043	29.9
Number of Students	100,586	
3 or Higher / %	56,192	55.9
Mean Grade	2.80	
Standard Deviation	1.49	

Section I: Multiple Choice

$$\frac{\text{Number Correct}}{\text{(out of 75)}} \times 1.0000 = \frac{\text{Weighted Section I Score}}{\text{(Do not round.)}}$$

Section II: Free Response

Question 1 $\frac{\text{ }}{\text{(out of 9)}} \times 1.6666 = \frac{\text{ }}{\text{(Do not round)}}$

Question 2 $\frac{\text{ }}{\text{(out of 10)}} \times 1.5000 = \frac{\text{ }}{\text{(Do not round)}}$

Question 3 $\frac{\text{ }}{\text{(out of 9)}} \times 1.6666 = \frac{\text{ }}{\text{(Do not round)}}$

Question 4 $\frac{\text{ }}{\text{(out of 15)}} \times 0.5000 = \frac{\text{ }}{\text{(Do not round)}}$

Question 5 $\frac{\text{ }}{\text{(out of 9)}} \times 1.2500 = \frac{\text{ }}{\text{(Do not round)}}$

Question 6 $\frac{\text{ }}{\text{(out of 8)}} \times 1.4062 = \frac{\text{ }}{\text{(Do not round)}}$

$$SUM = \frac{\text{Weighted Section II Score}}{\text{(Do not round.)}}$$

AP Grade Conversion Chart

Composite Score Range*	AP Grade
100-150	5
81-99	4
62-80	3
49-61	2
0-48	1

*The candidates' scores are weighted as indicated on the exam sections. The Chief Faculty Consultant is responsible for converting composite scores to the 5-point AP scale.

Final Composite Score

$$\frac{\text{Weighted Section I Score}}{\text{ }} + \frac{\text{Weighted Section II Score}}{\text{ }} = \frac{\text{Composite Score}}{\text{(round to the nearest integer)}}$$