

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.***

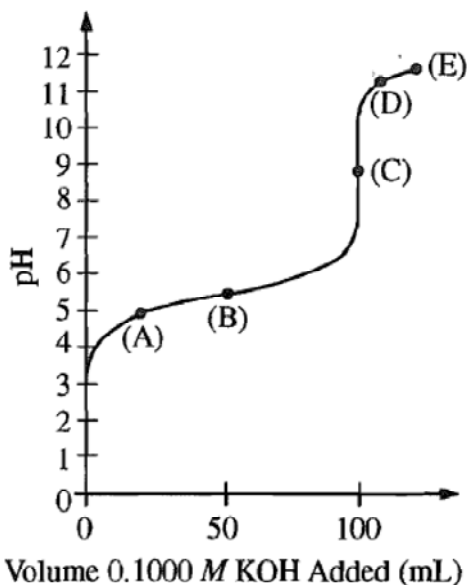
Questions 1-3 refer to the following types of elements in the periodic table.

- (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

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.
$$2 \text{KClO}_3(\text{s}) \xrightarrow[\text{MnO}_2]{\Delta} 2 \text{KCl}(\text{s}) + 3 \text{O}_2(\text{g})$$
- 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) $\frac{1}{3} \left(\frac{1}{22.4} \right)$ mol
 B) $\frac{1}{2} \left(\frac{1}{22.4} \right)$ mol
 C) $\frac{2}{3} \left(\frac{1}{22.4} \right)$ mol
 D) $\frac{3}{2} \left(\frac{1}{22.4} \right)$ mol
 E) $2 \left(\frac{1}{22.4} \right)$ 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 $\text{H}_3\text{PO}_4(\text{l})$?

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 $\text{HI}(\text{g})$ in the equilibrium mixture?

- I. Adding $\text{H}_2(\text{g})$
 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 ?

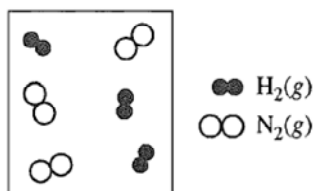
A) 1.2×10^{23}
 B) 3.0×10^{23}
 C) 6.0×10^{23}
 D) 1.2×10^{24}
 E) 6.0×10^{24}

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

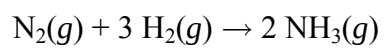
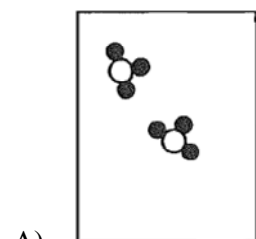
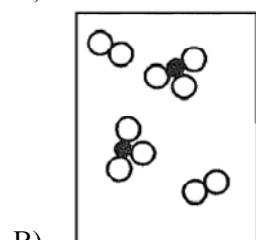
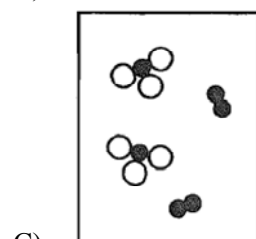
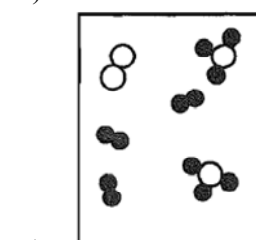
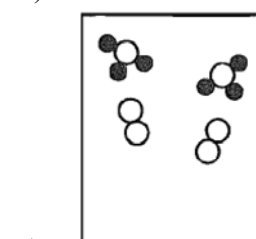
A) Si
 B) S
 C) C
 D) Mg
 E) Cs

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?



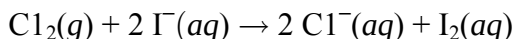
42. Equal masses of He and Ne are placed in a sealed container. What is the partial pressure of He if the total pressure in the container is 6 atm?

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

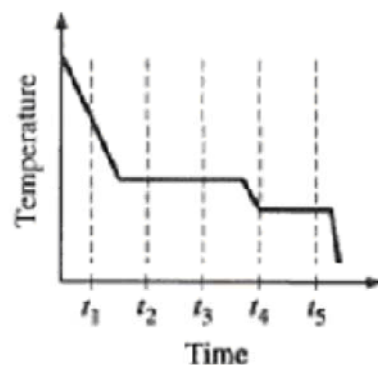
44.



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?

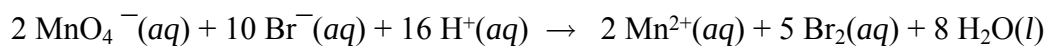
A) t_1
 B) t_2
 C) t_3
 D) t_4
 E) t_5

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

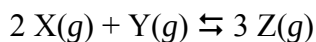
53. A sample of 10.0 mol of butyric acid, $\text{HC}_4\text{H}_7\text{O}_2$, a weak acid, is dissolved in 1000. g of water to make a 10.0-molal solution. Which of the following would be the best method to determine the molarity of the solution? (In each case, assume that no additional information is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



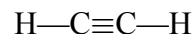
The reaction mixture represented above is at equilibrium at 298 K, and the molar concentrations are $[\text{X}] = 2.0 \text{ M}$, $[\text{Y}] = 0.5 \text{ M}$, and $[\text{Z}] = 4.0 \text{ M}$. What is the value of the equilibrium constant for the reaction at 298K?

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.



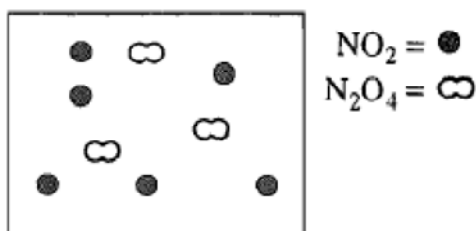
What is the hybridization of the carbon atoms in a molecule of ethyne, represented above?

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.

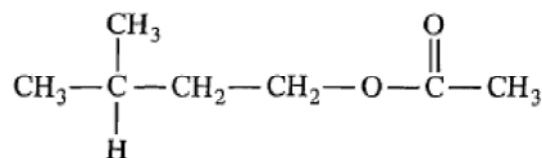


The diagram above represents a mixture of $\text{NO}_2(g)$ and $\text{N}_2\text{O}_4(g)$ in a 1.0 L container at a given temperature. The two gases are in equilibrium according to the equation $2 \text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)$.

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^+ .

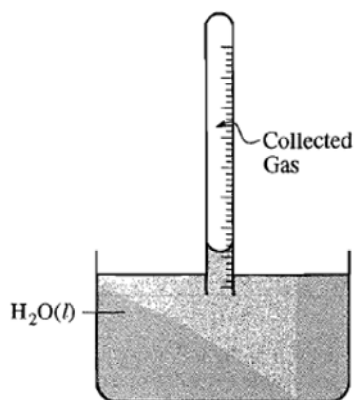
61.



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

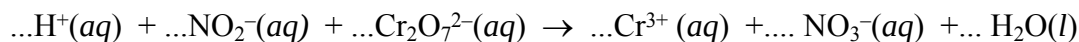
65.



In a laboratory experiment, H₂(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 H₂O(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

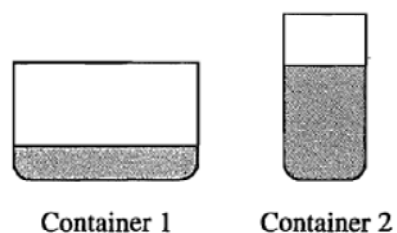
71. Of the following single bonds, which is the LEAST polar?

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)

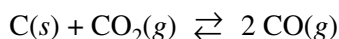
- A) 386,000 sec
 - B) 193,000 sec
 - C) 96,500 sec
 - D) 48,200 sec
 - E) 24,100 sec
75. Which of the following molecules has an angular (bent) geometry that is commonly represented as a resonance hybrid of two or more electron-dot structures?
- A) CO_2
 - B) O_3
 - C) CH_4
 - D) BeF_2
 - E) OF_2

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.
-

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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.

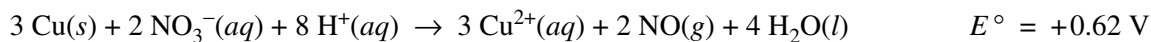
In the second experiment, a student is given 2.94 g of a mixture containing anhydrous MgCl_2 and KNO_3 . To determine the percentage by mass of MgCl_2 in the mixture, the student uses excess $\text{AgNO}_3(aq)$ to precipitate the chloride ion as $\text{AgCl}(s)$.

- (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.

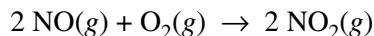


- (a) Using the information above and in the table below, calculate the standard reduction potential, E° , for the reduction of NO_3^- in acidic solution.

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.**

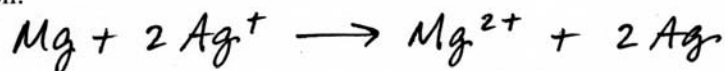
Answer Question 4 below. The Section II score weighting for this question is 10 percent.

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.

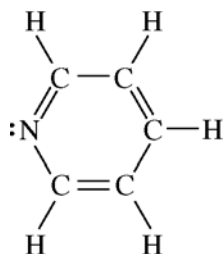


- (e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:
- (i) The geometric shape of the XeO_3 molecule
 - (ii) The hybridization of the valence orbitals of xenon in XeF_4
- (f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

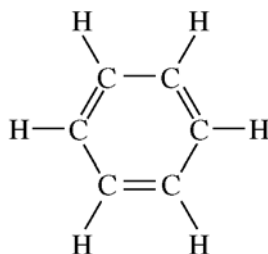
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6. Answer the following questions by using principles of molecular structure and intermolecular forces.

- (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.

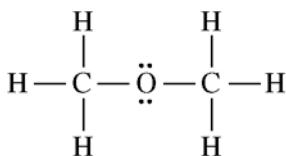


Pyridine

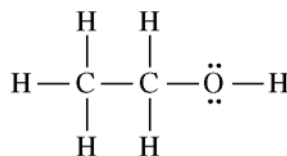


Benzene

- (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) 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.
- (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.

STOP

END OF EXAM

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

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

PERIODIC TABLE OF THE ELEMENTS																	
1																	2
H																	He
1.008																	4.00
3	4															9	10
Li	Be															F	Ne
6.94	9.01															19.00	20.18
11	12															17	18
Na	Mg															Cl	Ar
22.99	24.30															35.45	39.95
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)							
</																	

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 atm = 760 mm Hg

$= 760 \text{ torr}$

STP = 0.00°C and 1.0 atm

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

APPENDIX - ANSWERS

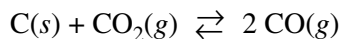
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Multiple-choice key transcribed from the matching supplied source.

Question	Answer	Question	Answer	Question	Answer
1	A	26	D	51	C
2	E	27	D	52	C
3	C	28	C	53	D
4	C	29	B	54	D
5	E	30	B	55	E
6	B	31	C	56	A
7	A	32	C	57	A
8	E	33	A	58	D
9	E	34	D	59	B
10	C	35	C	60	B
11	A	36	A	61	D
12	C	37	A	62	B
13	A	38	D	63	B
14	C	39	E	64	D
15	B	40	A	65	C
16	E	41	E	66	E
17	A	42	E	67	B
18	C	43	C	68	B
19	C	44	B	69	A
20	E	45	D	70	B
21	B	46	A	71	C
22	C	47	B	72	E
23	B	48	B	73	E
24	B	49	E	74	B
25	A	50	E	75	B

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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.)

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

- (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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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>
--	---

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.
---	--

- (b) Use the data above to

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

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

- (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.
---	--

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.
---	---

- (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

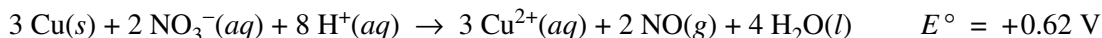
$0.0191 \text{ mol MgCl}_2 \times \frac{95.20 \text{ g MgCl}_2}{1 \text{ mol MgCl}_2} = 1.82 \text{ g MgCl}_2$ $\frac{1.82 \text{ g MgCl}_2}{2.94 \text{ g sample}} \times 100\% = 61.9\% \text{ MgCl}_2 \text{ by mass}$	One point is earned for calculating the correct percentage.
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Question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

- (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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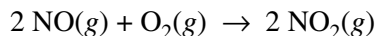
- (c) Predict whether the value of the standard entropy change, ΔS° , for the overall reaction is greater than 0, less than 0, or equal to 0. Justify your prediction.

$\Delta S^\circ > 0$. 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.
--	--

(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.
--	--

- (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>
---	--

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>
---	--

- (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>
--	---

(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.)
---	---

- (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.
---	---

- (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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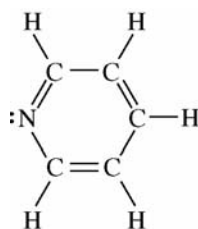
- (f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

<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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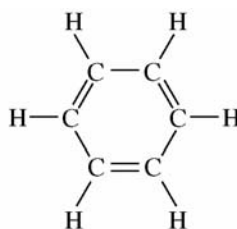
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Question 6

- (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



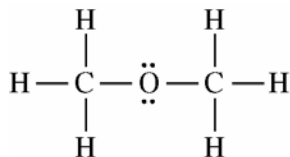
Benzene

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.

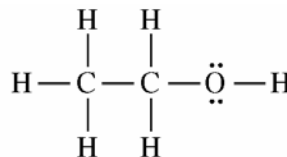
One point is earned for identifying a relevant structural difference between pyridine and benzene.

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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2008 SCORING GUIDELINES

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.