Chemical Calculations

The following list summarizes types of problems either explicitly or implicitly included in the preceding material. Attention should be given to significant figures, precision of measured values, and the use of logarithmic and exponential relationships. Critical analysis of the reasonableness of results is to be encouraged.

1. Percentage composition
2. Empirical and molecular formulas from experimental data
3. Molar masses from gas density, freezing-point and boiling-point measurements
4. Gas laws, including the ideal gas law, Dalton's law and Graham's law
5. Stoichiometric relations using the concept of the mole; titration calculations
6. Mole fractions; molar and molal solutions
7. Faraday's laws of electrolysis
8. Equilibrium constants and their applications, including their use for simultaneous equilibria
9. Standard electrode potentials and their use; Nernst equation
10. Thermodynamic and thermochemical calculations
11. Kinetics calculations

THE EXAM

The AP Chemistry Exam has two main parts, Section I and Section II, that contribute equally (50 percent each) toward the final score. Section I consists of 75 multiple-choice questions that cover a broad range of topics. Section II consists of six free-response questions: three multipart quantitative questions, one question on writing balanced chemical equations and answering a short question for three different sets of reactants, and two multipart questions that are essentially nonquantitative.

Teachers should not try to prepare students to answer every question in Section I of the exam. To be broad enough in scope to give every student who has covered an adequate amount of material an opportunity to make a good showing, the exam must be so comprehensive that no student should be expected to make a perfect or near-perfect score.

A period of 90 minutes is allotted for Section I of the exam. Section II is divided into two parts: for Part A (55 minutes), students are allowed the use of a calculator, but for Part B (40 minutes), no calculators are permitted.

Every Section II of the exam will contain one quantitative question that is based on chemical equilibrium and one question that is based on laboratory. The laboratory question may appear in Part A and be quantitative, or it may appear in Part B and require little or no calculation.

In past AP Chemistry Examinations, the practice for writing units associated with changes in thermodynamic quantities in given reactions has been to use kJ/mol and kJ/(mol·K) for energy and entropy changes, respectively. Starting in May 2012, the use of the term "mol_{rxn}" (read aloud as "mole reaction" or "mole of reaction") in thermodynamic units will be phased in as a move toward a standard practice in the AP Chemistry Examination. Specifically, the term mol_{rxn} will be used in the denominator when quantities such as changes in enthalpy, Gibbs free energy, and entropy are expressed in the context of given reactions. For example, consider the reaction represented below.

$$2\,Al(s) + 3\,Cl_2(g) \rightarrow 2\,AlCl_3(s)$$

For this reaction, $\Delta H^\circ = -1411\ kJ/mol_{rxn}$, $\Delta G^\circ = -1260\ kJ/mol_{rxn}$, and $\Delta S^\circ = -505\ J/(mol_{rxn} \cdot K)$. In each case, the values given are for the reaction that occurs as written, specifically with the coefficients referring to numbers of moles of substances (not individual atoms or molecules).

Calculators

The policy regarding the use of calculators on the AP Chemistry Exam was developed to address the rapid expansion of the capabilities of scientific calculators, which include not only programming and graphing functions but also the availability of stored equations and other data. For the section of the exam in which calculators are permitted, students should be allowed to use the calculators to which they are accustomed, except as noted below.* On the other hand, they should not have access to information in their calculators that is not available to other students, if that information is needed to answer the questions.

Therefore, calculators are not permitted on the *multiple-choice section* of the AP Chemistry Exam. The purpose of the multiple-choice section is to assess the breadth of students' knowledge and understanding of the basic concepts of chemistry. The multiple-choice questions emphasize conceptual understanding as well as qualitative and simple quantitative applications of principles. Many chemical and physical principles and relationships are quantitative by nature and can be expressed as equations. Knowledge of the underlying basic definitions and principles, expressed as equations, is a part of the content of chemistry that should be learned by chemistry students and will continue to be assessed in the multiple-choice section. However, any numeric calculations that require use of these equations in the multiple-choice section will be limited to simple arithmetic so that they can be done quickly, either mentally or with paper and pencil. Also, in some questions the answer choices differ by several orders of magnitude so that the questions can be answered by estimation. Refer to sample questions on pages 15–17 (#6, 8, 11, 12, 16, and 17), which can be answered using simple arithmetic or by estimation. Students should be encouraged to develop their skills not only in estimating answers but also in recognizing answers that are physically unreasonable or unlikely.

Calculators (with the exceptions previously noted) will be allowed only during the first 55 minutes (Part A) of the free-response section of the exam. During this time, students will work on three problems. **Any programmable or graphing calculator may be used, and students will NOT be required to erase their calculator memories before or after the exam.** Students will not be allowed to move on to the

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* **Exceptions to calculator use.** Calculators that are not permitted are PowerBooks and portable/handheld computers; electronic writing pads or pen-input/stylus-driven devices (e.g., Palm, PDAs, Casio ClassPad 300); pocket organizers; models with QWERTY (i.e., typewriter) keypads (e.g., TI-92 Plus, Voyage 200); models with paper tapes; models that make noise or "talk"; models that require an electrical outlet; cell phone calculators. Students may not share calculators.

last portion of the free-response section until time is called and all calculators are put away. For the last 40 minutes (Part B) of the exam, students will work without calculators on the remaining portion of the free-response section.

Equation Tables

Tables containing equations commonly used in chemistry are printed in the free-response (Section II) exam booklet for students to use when taking the free-response section. The equation tables are NOT permitted for use with the multiple-choice section. In general, the equations for each year's exam are printed and distributed with the Course Description at least a year in advance so that students can become accustomed to using them throughout the year. However, because the equation tables will be provided with the exam, students will NOT be allowed to bring their own copies to the exam room. The latest version of the equation tables is shown on pages 12–13 of this booklet.

One of the purposes of providing the tables of commonly used equations for use with the free-response section is to address the issue of equity for those students who do not have access to equations stored in their calculators. The availability of these equations to all students means that in the scoring of the free-response sections, little or no credit will be awarded for simply writing down equations or for answers unsupported by explanations or logical development.

The equations in the tables express relationships that are encountered most frequently in an AP Chemistry course and exam. However, they do not include all equations that might possibly be used. For example, they do not include many equations that can be derived by combining others in the tables. Nor do they include equations that are simply special cases of any that are in the tables. Students are responsible for understanding the physical principles that underlie each equation and for knowing the conditions for which each equation is applicable.

The equations are grouped in tables according to major content category. Within each table, the symbols used for the variables in that table are defined. However, in some cases the same symbol is used to represent different quantities in different tables. It should be noted that there is no uniform convention among textbooks for the symbols used in writing equations. The equation tables follow many common conventions, but in some cases consistency was sacrificed for the sake of clarity.

In summary, the purpose of minimizing numerical calculations in both sections of the exam and providing equations with the free-response section is to place greater emphasis on the understanding and application of fundamental chemical principles and concepts. For solving problems and writing essays, a sophisticated programmable or graphing calculator, or the availability of stored equations, is no substitute for a thorough grasp of the chemistry involved.

Sample Multiple-Choice Questions

The following multiple-choice questions provide a representative subset of those used in previous AP Chemistry Exams. There are two types of multiple-choice questions. The first type consists of five lettered headings followed by a list of numbered phrases. For each numbered phrase, the student is instructed to select the one heading that is most closely related to it. Each heading may be used once, more than once, or not at all in each group.

Questions 1-3 refer to atoms of the following elements.

(A) Lithium
(B) Carbon
(C) Nitrogen
(D) Oxygen
(E) Fluorine

1. In the ground state, have only 1 electron in each of the three *p* orbitals

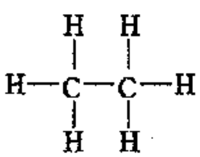
2. Have the smallest atomic radius

3. Have the smallest value for first ionization energy

The majority of the multiple-choice questions consist of questions or incomplete statements followed by five suggested answers or completions. The student is instructed to select the one that is best in each case.

4. Which of the following species is NOT planar?

(A) CO_3^{2-}
(B) NO_3^-
(C) ClF_3
(D) BF_3
(E) PCl_3



5. The hybridization of the carbon atoms in the molecule represented above can be described as

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

6. The half-life of ^{55}Cr is about 2.0 hours. The delivery of a sample of this isotope from the reactor to a certain laboratory requires 12 hours. About what mass of such material should be shipped in order that 1.0 mg of ^{55}Cr is delivered to the laboratory?

   (A) 130 mg
   (B) 64 mg
   (C) 32 mg
   (D) 11 mg
   (E) 1.0 mg

7. At constant temperature, the behavior of a sample of a real gas more closely approximates that of an ideal gas as its volume is increased because the

   (A) collisions with the walls of the container become less frequent
   (B) average molecular speed decreases
   (C) molecules have expanded
   (D) average distance between molecules becomes greater
   (E) average molecular kinetic energy decreases

8. A sealed vessel contains 0.200 mol of oxygen gas, 0.100 mol of nitrogen gas, and 0.200 mol of argon gas. The total pressure of the gas mixture is 5.00 atm. The partial pressure of the argon is

   (A) 0.200 atm
   (B) 0.500 atm
   (C) 1.00 atm
   (D) 2.00 atm
   (E) 5.00 atm

9. Which of the following accounts for the fact that liquid CO_2 is <u>not</u> observed when a piece of solid CO_2 (dry ice) is placed on a lab bench?

   (A) The phase diagram for CO_2 has no triple point.
   (B) The normal boiling point of CO_2 is lower than its normal freezing point.
   (C) $CO_2(s)$ is a molecular solid.
   (D) The critical pressure for CO_2 is approximately 1 atm.
   (E) The triple point for CO_2 is above 1 atm.

10. If ΔG for a certain reaction has a negative value at 298 K, which of the following must be true?

    I. The reaction is exothermic.
    II. The reaction occurs spontaneously at 298 K.
    III. The rate of the reaction is fast at 298 K.

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

$$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$$

11. A mixture of gases containing 0.20 mol of SO_2 and 0.20 mol of O_2 in a 4.0 L flask reacts to form SO_3. If the temperature is 25°C, what is the pressure in the flask after reaction is complete?

    (A) $\frac{0.4(0.082)(298)}{4}$ atm

    (B) $\frac{0.3(0.082)(298)}{4}$ atm

    (C) $\frac{0.2(0.082)(298)}{4}$ atm

    (D) $\frac{0.2(0.082)(25)}{4}$ atm

    (E) $\frac{0.3(0.082)(25)}{4}$ atm

12. A solution prepared by mixing 10 mL of 1 *M* HCl and 10 mL of 1.2 *M* NaOH has a pH of

    (A) 0 (B) 1 (C) 7 (D) 13 (E) 14

13. All of the following reactions can be defined as Lewis acid-base reactions EXCEPT

    (A) $Al(OH)_3(s) + OH^-(aq) \rightarrow Al(OH)_4^-(aq)$
    (B) $Cl_2(g) + H_2O(l) \rightarrow HOCl(aq) + H^+(aq) + Cl^-(aq)$
    (C) $SnCl_4(s) + 2\ Cl^-(aq) \rightarrow SnCl_6^{2-}(aq)$
    (D) $NH_4^+(g) + NH_2^-(g) \rightarrow 2\ NH_3(g)$
    (E) $H^+(aq) + NH_3(aq) \rightarrow NH_4^+(aq)$

14. Which of the following represents a process in which a species is reduced?

    (A) $Ca(s) \rightarrow Ca^{2+}(aq)$
    (B) $Hg(l) \rightarrow Hg_2^{2+}(aq)$
    (C) $Fe^{2+}(aq) \rightarrow Fe^{3+}(aq)$
    (D) $NO_3^-(aq) \rightarrow NO(g)$
    (E) $SO_3^{2-}(aq) \rightarrow SO_4^{2-}(aq)$

$$Cd^{2+}(aq) + 2e^- \rightleftarrows Cd(s) \quad E^\circ = -0.41\ V$$
$$Cu^+(aq) + e^- \rightleftarrows Cu(s) \quad E^\circ = +0.52\ V$$
$$Ag^+(aq) + e^- \rightleftarrows Ag(s) \quad E^\circ = +0.80\ V$$

15. Based on the standard electrode potentials given above, which of the following is the strongest reducing agent?

    (A) $Cd(s)$ (B) $Cd^{2+}(aq)$ (C) $Cu(s)$ (D) $Ag(s)$ (E) $Ag^+(aq)$

16. A sample of $CaCO_3$ (molar mass 100. g) was reported as being 30. percent Ca. Assuming no calcium was present in any impurities, the percent of $CaCO_3$ in the sample is

(A) 30% (B) 40% (C) 70% (D) 75% (E) 100%

$$2\ Al(s) + 6\ HCl(aq) \rightarrow 2\ AlCl_3(aq) + 3\ H_2(g)$$

17. According to the reaction represented above, about how many grams of aluminum (atomic mass 27 g) are necessary to produce 0.50 mol of hydrogen gas at 25°C and 1.00 atm?

(A) 1.0 g
(B) 9.0 g
(C) 14 g
(D) 27 g
(E) 56 g

$$\ldots Cr_2O_7^{2-}(aq) + \ldots HNO_2(aq) + \ldots H^+(aq) \rightarrow \ldots Cr^{3+}(aq) + \ldots NO_3^-(aq) + \ldots H_2O(l)$$

18. When the equation for the redox reaction represented above is balanced and all coefficients are reduced to lowest whole-number terms, the coefficient for $H_2O(l)$ is

(A) 3 (B) 4 (C) 5 (D) 6 (E) 8

19. Which of the following equations represents the net reaction that occurs when gaseous hydrofluoric acid reacts with solid silicon dioxide?

(A) $2\ H^+(aq) + 2\ F^-(aq) + SiO_2(s) \rightarrow SiOF_2(s) + H_2O(l)$
(B) $4\ F^-(aq) + SiO_2(s) \rightarrow SiF_4(g) + 2\ O^{2-}(aq)$
(C) $4\ HF(g) + SiO_2(s) \rightarrow SiF_4(g) + 2\ H_2O(l)$
(D) $4\ HF(g) + SiO_2(s) \rightarrow Si(s) + 2\ F_2(g) + 2\ H_2O(l)$
(E) $2\ H_2F(g) + Si_2O_2(s) \rightarrow 2\ SiF(g) + 2\ H_2O(l)$

20. The ionization constant for acetic acid is 1.8×10^{-5}; that for hydrocyanic acid is 4×10^{-10}. In 0.1 *M* solutions of sodium acetate and sodium cyanide, it is true that

(A) $[H^+]$ equals $[OH^-]$ in each solution
(B) $[H^+]$ exceeds $[OH^-]$ in each solution
(C) $[H^+]$ of the sodium acetate solution is less than that of the sodium cyanide solution
(D) $[OH^-]$ of the sodium acetate solution is less than that of the sodium cyanide solution
(E) $[OH^-]$ for the two solutions is the same

$$HCl > HC_2H_3O_2 > HCN > H_2O > NH_3$$

21. Five acids are listed above in the order of decreasing acid strength. Which of the following reactions must have an equilibrium constant with a value less than 1?

(A) $HCl(aq) + CN^-(aq) \rightleftarrows HCN(aq) + Cl^-(aq)$
(B) $HCl(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + Cl^-(aq)$
(C) $HC_2H_3O_2(aq) + OH^-(aq) \rightleftarrows C_2H_3O_2^-(aq) + H_2O(l)$
(D) $H_2O(aq) + NH_2^-(aq) \rightleftarrows NH_3(aq) + OH^-(aq)$
(E) $HCN(aq) + C_2H_3O_2^-(aq) \rightleftarrows HC_2H_3O_2(aq) + CN^-(aq)$

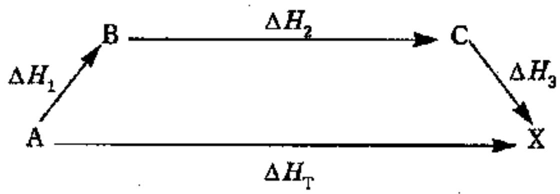
Experiment	*Initial* [X] *(mol L⁻¹)*	*Initial* [Y] *(mol L⁻¹)*	*Initial Rate of Formulation of* Z *(mol L⁻¹ min⁻¹)*
1	0.10	0.30	4.0×10^{-4}
2	0.20	0.60	1.6×10^{-3}
3	0.20	0.30	4.0×10^{-4}

22. The data in the table above were obtained for the reaction X + Y → Z. Which of the following is the rate law for the reaction?

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

$$A \rightarrow X$$

23. The enthalpy change for the reaction represented above is ΔH_T. This reaction can be broken down into a series of steps as shown in the diagram:



A relationship that must exist among the various enthalpy changes is

(A) $\Delta H_T - \Delta H_1 - \Delta H_2 - \Delta H_3 = 0$
(B) $\Delta H_T + \Delta H_1 + \Delta H_2 + \Delta H_3 = 0$
(C) $\Delta H_3 - (\Delta H_1 + \Delta H_2) = \Delta H_T$
(D) $\Delta H_2 - (\Delta H_3 + \Delta H_1) = \Delta H_T$
(E) $\Delta H_T + \Delta H_2 = \Delta H_1 + \Delta H_3$

24. What formula would be expected for a binary compound of barium and nitrogen?

(A) Ba_3N_2 (B) Ba_2N_3 (C) Ba_2N (D) BaN_2 (E) BaN

25. All of the following statements about the nitrogen family of elements are true EXCEPT:

    (A) It contains both metals and nonmetals.
    (B) The electronic configuration of the valence shell of the atom is ns^2np^3.
    (C) The only oxidation states exhibited by members of this family are −3, 0, +3, +5.
    (D) The atomic radii increase with increasing atomic number.
    (E) The boiling points increase with increasing atomic number.

26. Of the following organic compounds, which is LEAST soluble in water at 298 K?

    (A) CH_3OH, methanol
    (B) $CH_3CH_2CH_2OH$, 1-propanol
    (C) C_6H_{14}, hexane
    (D) $C_6H_{12}O_6$, glucose
    (E) CH_3COOH, ethanoic (acetic) acid

27. Which of the following salts forms a basic solution when dissolved in water?

    (A) $NaCl$
    (B) $(NH_4)_2SO_4$
    (C) $CuSO_4$
    (D) K_2CO_3
    (E) NH_4NO_3

28. The molecular mass of a substance can be determined by measuring which of the following?

    I. Osmotic pressure of a solution of the substance
    II. Freezing point depression of a solution of the substance
    III. Density of the gas (vapor) phase of the substance

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

CollegeBoard
Advanced Placement Program

AP® Chemistry
2007 Free-Response Questions

The College Board: Connecting Students to College Success

INFORMATION IN THE TABLE BELOW AND IN THE TABLES ON PAGES 4-6 MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

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

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

STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

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

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

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

$\lambda = \dfrac{h}{mv} \qquad p = mv$

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

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

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

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

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

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

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

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

EQUILIBRIUM

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

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

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

$pH = -\log[H^+]$, $pOH = -\log[OH^-]$
$14 = pH + pOH$

$pH = pK_a + \log\dfrac{[A^-]}{[HA]}$

$pOH = pK_b + \log\dfrac{[HB^+]}{[B]}$

$pK_a = -\log K_a$, $pK_b = -\log K_b$

$K_p = K_c(RT)^{\Delta n}$,
where Δn = moles product gas − moles reactant gas

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

THERMOCHEMISTRY/KINETICS

$\Delta S^\circ = \sum S^\circ$ products $-\sum S^\circ$ reactants

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

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

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

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

$q = mc\Delta T$

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

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

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

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

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

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

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

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

$$K = °C + 273$$

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

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

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

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

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

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

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

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

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

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

$$\log K = \frac{nE°}{0.0592}$$

Gas constant, $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
$= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$
$= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$

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

K_f for H_2O = $1.86 \text{ K kg mol}^{-1}$

K_b for H_2O = $0.512 \text{ K kg mol}^{-1}$

1 atm = 760 mm Hg
= 760 torr

STP = 0.00°C and 1.0 atm

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

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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.

$$HF(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + F^-(aq) \qquad K_a = 7.2 \times 10^{-4}$$

1. Hydrofluoric acid, $HF(aq)$, dissociates in water as represented by the equation above.

   (a) Write the equilibrium-constant expression for the dissociation of $HF(aq)$ in water.

   (b) Calculate the molar concentration of H_3O^+ in a 0.40 M $HF(aq)$ solution.

   $HF(aq)$ reacts with $NaOH(aq)$ according to the reaction represented below.

   $$HF(aq) + OH^-(aq) \rightarrow H_2O(l) + F^-(aq)$$

   A volume of 15 mL of 0.40 M $NaOH(aq)$ is added to 25 mL of 0.40 M $HF(aq)$ solution. Assume that volumes are additive.

   (c) Calculate the number of moles of $HF(aq)$ remaining in the solution.

   (d) Calculate the molar concentration of $F^-(aq)$ in the solution.

   (e) Calculate the pH of the solution.

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$N_2(g) + 3\,F_2(g) \rightarrow 2\,NF_3(g)$ $\Delta H^\circ_{298} = -264$ kJ mol^{-1}; $\Delta S^\circ_{298} = -278$ J K^{-1} mol^{-1}

2. The following questions relate to the synthesis reaction represented by the chemical equation in the box above.

(a) Calculate the value of the standard free energy change, ΔG°_{298}, for the reaction.

(b) Determine the temperature at which the equilibrium constant, K_{eq}, for the reaction is equal to 1.00. (Assume that ΔH° and ΔS° are independent of temperature.)

(c) Calculate the standard enthalpy change, ΔH°, that occurs when a 0.256 mol sample of $NF_3(g)$ is formed from $N_2(g)$ and $F_2(g)$ at 1.00 atm and 298 K.

The enthalpy change in a chemical reaction is the difference between energy absorbed in breaking bonds in the reactants and energy released by bond formation in the products.

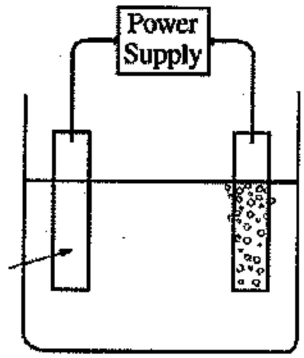
(d) How many bonds are formed when two molecules of NF_3 are produced according to the equation in the box above?

(e) Use both the information in the box above and the table of average bond enthalpies below to calculate the average enthalpy of the F – F bond.

Bond	Average Bond Enthalpy (kJ mol^{-1})
N≡N	946
N–F	272
F–F	?

GO ON TO THE NEXT PAGE.

$Cu^{2+}(aq) + 2\,e^{-} \longrightarrow Cu(s)$



3. An external direct-current power supply is connected to two platinum electrodes immersed in a beaker containing 1.0 *M* $CuSO_4(aq)$ at 25°C, as shown in the diagram above. As the cell operates, copper metal is deposited onto one electrode and $O_2(g)$ is produced at the other electrode. The two reduction half-reactions for the overall reaction that occurs in the cell are shown in the table below.

Half-Reaction	$E°$(V)
$O_2(g) + 4\,H^+(aq) + 4\,e^- \rightarrow 2\,H_2O(l)$	+1.23
$Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s)$	+0.34

(a) On the diagram, indicate the direction of electron flow in the wire.

(b) Write a balanced net ionic equation for the electrolysis reaction that occurs in the cell.

(c) Predict the algebraic sign of $\Delta G°$ for the reaction. Justify your prediction.

(d) Calculate the value of $\Delta G°$ for the reaction.

An electric current of 1.50 amps passes through the cell for 40.0 minutes.

(e) Calculate the mass, in grams, of the $Cu(s)$ that is deposited on the electrode.

(f) Calculate the dry volume, in liters measured at 25°C and 1.16 atm, of the $O_2(g)$ that is produced.

STOP

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

CHEMISTRY
Part B
Time—40 minutes
NO CALCULATORS MAY BE USED FOR PART B.

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

4. For each of the following three reactions, 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:

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

(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

(a) A solution of sodium hydroxide is added to a solution of lead(II) nitrate.

(i) Balanced equation:

(ii) If 1.0 L volumes of 1.0 *M* solutions of sodium hydroxide and lead(II) nitrate are mixed together, how many moles of product(s) will be produced? Assume the reaction goes to completion.

GO ON TO THE NEXT PAGE.

(b) Excess nitric acid is added to solid calcium carbonate.

(i) Balanced equation:

(ii) Briefly explain why statues made of marble (calcium carbonate) displayed outdoors in urban areas are deteriorating.

(c) A solution containing silver(I) ion (an oxidizing agent) is mixed with a solution containing iron(II) ion (a reducing agent).

(i) Balanced equation:

(ii) If the contents of the reaction mixture described above are filtered, what substance(s), if any, would remain on the filter paper?

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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.

$$5\,Fe^{2+}(aq) + MnO_4^-(aq) + 8\,H^+(aq) \rightarrow 5\,Fe^{3+}(aq) + Mn^{2+}(aq) + 4\,H_2O(l)$$

5. The mass percent of iron in a soluble iron(II) compound is measured using a titration based on the balanced equation above.

   (a) What is the oxidation number of manganese in the permanganate ion, $MnO_4^-(aq)$?

   (b) Identify the reducing agent in the reaction represented above.

   The mass of a sample of the iron(II) compound is carefully measured before the sample is dissolved in distilled water. The resulting solution is acidified with $H_2SO_4(aq)$. The solution is then titrated with $MnO_4^-(aq)$ until the end point is reached.

   (c) Describe the color change that occurs in the flask when the end point of the titration has been reached. Explain why the color of the solution changes at the end point.

   (d) Let the variables g, M, and V be defined as follows:

   g = the mass, in grams, of the sample of the iron(II) compound

   M = the molarity of the $MnO_4^-(aq)$ used as the titrant

   V = the volume, in liters, of $MnO_4^-(aq)$ added to reach the end point

   In terms of these variables, the number of moles of $MnO_4^-(aq)$ added to reach the end point of the titration is expressed as $M \times V$. Using the variables defined above, the molar mass of iron (55.85 g mol^{-1}), and the coefficients in the balanced chemical equation, write the expression for each of the following quantities.

   (i) The number of moles of iron in the sample

   (ii) The mass of iron in the sample, in grams

   (iii) The mass percent of iron in the compound

   (e) What effect will adding too much titrant have on the experimentally determined value of the mass percent of iron in the compound? Justify your answer.

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6. Answer the following questions, which pertain to binary compounds.

   (a) In the box provided below, draw a complete Lewis electron-dot diagram for the IF_3 molecule.

   (b) On the basis of the Lewis electron-dot diagram that you drew in part (a), predict the molecular geometry of the IF_3 molecule.

   (c) In the SO_2 molecule, both of the bonds between sulfur and oxygen have the same length. Explain this observation, supporting your explanation by drawing in the box below a Lewis electron-dot diagram (or diagrams) for the SO_2 molecule.

   (d) On the basis of your Lewis electron-dot diagram(s) in part (c), identify the hybridization of the sulfur atom in the SO_2 molecule.

The reaction between $SO_2(g)$ and $O_2(g)$ to form $SO_3(g)$ is represented below.

$$2\,SO_2(g) + O_2(g) \rightleftarrows 2\,SO_3(g)$$

The reaction is exothermic. The reaction is slow at 25°C; however, a catalyst will cause the reaction to proceed faster.

   (e) Using the axes provided on the next page, draw the complete potential-energy diagram for both the catalyzed and uncatalyzed reactions. Clearly label the curve that represents the catalyzed reaction.

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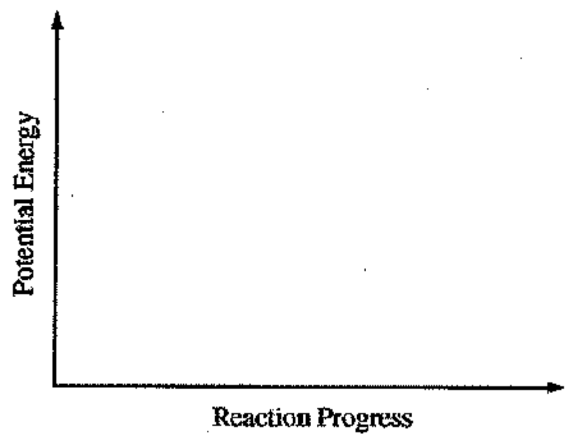

(f) Predict how the ratio of the equilibrium pressures, $\frac{p_{SO_2}}{p_{SO_3}}$, would change when the temperature of the uncatalyzed reaction mixture is increased. Justify your prediction.

(g) How would the presence of a catalyst affect the change in the ratio described in part (f)? Explain.

STOP

END OF EXAM