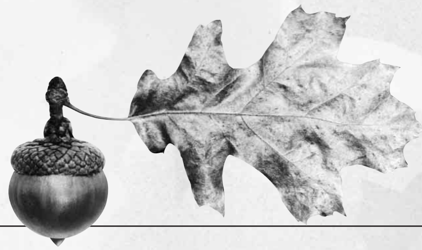

Advanced Placement Program® Course Description

Chemistry

May 2000, May 2001

The College Board
Educational Excellence for All Students

Introduction

The Advanced Placement Program® consists of 33 college-level courses and exams in 19 disciplines designed for highly motivated students in secondary schools. Its exceptional reputation is made possible by the close cooperation of secondary schools, colleges, and the College Board. More than 2,900 universities and colleges worldwide grant credit, advanced placement, or both to students who have performed satisfactorily on the exams, and approximately 1,400 institutions grant sophomore standing to students who have demonstrated their competence in three or more of these exams.

Each course is developed by a committee made up of college faculty and AP teachers. Members of these Development Committees are appointed by the College Board and serve for overlapping terms of up to four years. Courses and exams are now available in the following subject areas:

Art: Art History, Studio Art (Drawing and General)
Biology
Calculus: AB, BC
Chemistry
Computer Science: A* and AB
Economics: Macroeconomics*, Microeconomics*
English: English Language and Composition, English Literature and Composition, International English Language
Environmental Science*
French: French Language, French Literature
German Language
Geography: Human Geography* (2001)
Government and Politics: Comparative*, U.S.*
History: European, U.S.
Latin: Literature, Vergil
Music Theory
Physics: B, C: Electricity and Magnetism*, C: Mechanics*
Psychology*
Spanish: Language, Literature
Statistics*

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*This subject is the equivalent of a half-year college course.

Advanced Placement is a significant force in education, especially at the secondary level. Approximately 14,000 high schools throughout the world participate in the AP Program, and in May 1998, approximately 635,000 of their students took more than one million AP Exams.

You will find further information about the AP Program at the back of this Course Description, and on our website at

www.collegeboard.org/ap

Specific queries can also be addressed to any Regional Office of the College Board or to the National Office in New York (see the inside back cover of this booklet).

The AP Exams

AP Exams are offered throughout the world each May; see the outside back cover for the exam date in this subject. They are administered at participating schools or at multischool centers. Any school may participate; it need only file the AP Participation Form sent to all high schools every fall. Except for Studio Art — which consists of a portfolio assessment — all exams contain a free-response section (either essay or problem-solving) and another section consisting of multiple-choice questions. The modern language exams also contain a performance section that includes the recording of students' responses on audiotape, and the Music Theory exam includes a sight-singing task.

AP Chemistry

The AP Chemistry course is designed to be the equivalent of the general chemistry course usually taken during the first college year. For some students, this course enables them to undertake, as freshmen, second-year work in the chemistry sequence at their institution or to register in courses in other fields where general chemistry is a prerequisite. For other students, the AP Chemistry course fulfills the laboratory science requirement and frees time for other courses.

AP Chemistry should meet the objectives of a good general chemistry course. Students in such a course should attain a depth of understanding of fundamentals and a reasonable competence in dealing with chemical problems. The course should contribute to the development of the students' abilities to think clearly and to express their ideas, orally and in writing, with clarity and logic. The college course in general chemistry differs qualitatively from the usual first secondary school course in chemistry with respect to the kind of textbook used, the topics covered, the emphasis on chemical calculations and the mathematical formulation of principles, and the kind of laboratory work done by students. Quantitative differences appear in the number of topics treated, the time spent on the course by students, and the nature and the variety of experiments done in the laboratory. *Secondary schools that wish to offer an AP Chemistry course must be prepared to provide a laboratory experience equivalent to that of a typical college course.*

The AP Chemistry course is designed to be taken only after the successful completion of a first course in high school chemistry. A survey of students who took the 1986 AP Chemistry Examination indicates that the probability of achieving a grade of 3 or higher on the AP Chemistry Examination is significantly greater for students who successfully complete a first course in high school chemistry prior to undertaking the AP course. Thus it is strongly recommended that credit in a first-year high school chemistry course be a prerequisite for enrollment in an AP Chemistry class. *In addition, the recommended mathematics prerequisite for an AP Chemistry class is the successful completion of a second-year algebra course.*

The advanced work in chemistry should not displace any other part of the student's science curriculum. It is highly desirable that a student have a course in secondary school physics and a four-year college preparatory program in mathematics.

Time

Developing the requisite intellectual and laboratory skills required of an AP Chemistry candidate demands that adequate classroom and laboratory time be scheduled. Data obtained from a 1986 survey of students taking the AP Chemistry Examination indicate that performance improved as both total instructional time and time devoted to laboratory work increased.

Thus it is expected that a minimum of 290 minutes per week should be allotted for an AP Chemistry course. Of the total allocated time, a minimum of 90 minutes per week, preferably in one session, should be spent engaged in laboratory work. Time devoted to class and laboratory demonstrations should not be counted as part of the laboratory period.

It is assumed that the student will spend at least five hours a week in unsupervised individual study.

Textbooks

Current college textbooks are probably the best indicators of the level of the college general chemistry course that AP Chemistry is designed to represent. A contemporary college chemistry text that stresses principles and concepts and their relations to the descriptive chemistry on which they are based should be selected. Even the more advanced secondary school texts cannot serve adequately as texts for an AP course that is to achieve its objectives.

Among the many available high-quality college textbooks appropriate for AP Chemistry courses are the following (inclusion of a text in this list does not constitute endorsement by the College Board, ETS, or the AP Chemistry Development Committee):

Atkins, P., and J. Beran. *General Chemistry*, 2nd ed., revised. New York: W. H. Freeman, 1992.
Brown, T. L., H. E. LeMay, Jr., and B. E. Bursten. *Chemistry: The Central Science*, 7th ed. Upper Saddle River, N.J.: Prentice-Hall, 1997.
Chang, R. *Chemistry*, 6th ed. Boston: McGraw Hill, 1998.
Ebbing, D. D. *General Chemistry*, 5th ed. Boston: Houghton Mifflin, 1996.
Kotz, J. C., and P. Treichel. *Chemistry and Chemical Reactivity*, 4th ed. Fort Worth: Saunders, 1999.
Oxtoby, D. W., H. P. Gillis, and N. H. Nachtrieb. *Principles of Modern Chemistry*, 4th ed. Fort Worth: Saunders, 1999.
Petrucci, R. H., and W. S. Harwood. *General Chemistry*, 7th ed. Upper Saddle River, N.J.: Prentice-Hall, 1997.
Whitten, K. W., R. E. Davis, and M. P. Peck. *General Chemistry*, 5th ed. Fort Worth: Saunders, 1996.
Zumdahl, S. S. *Chemistry*, 4th ed. Boston: Houghton Mifflin, 1997.

Supplemental textbooks that can serve as resources for teachers include the following:

Robinson, J. D., J. D. Odom, and H. F. Holtzclaw. *General Chemistry with Qualitative Analysis*, 10th ed. Boston: Houghton Mifflin, 1997.
Segal, Bernice G. *Chemistry: Experiment and Theory*, 3rd ed. New York: Wiley, 1994.

Topics

The importance of the theoretical aspects of chemistry has brought about an increasing emphasis on these aspects of the content of general chemistry courses. Topics such as the structure of matter, kinetic theory of gases, chemical equilibria, chemical kinetics, and the basic concepts of thermodynamics are now being presented in considerable depth.

If the objectives of a college-level general chemistry course are to be achieved, the teaching should be done by a teacher who has completed an undergraduate major program in chemistry including at least a year's work in physical chemistry. Teachers with such training are best able to present a course with adequate breadth and depth and to develop the students' abilities to use the fundamental facts of the science in their reasoning. Because of the nature of the AP course, the teacher needs time *for extra preparation for both class and laboratory and should have a teaching load that is adjusted accordingly.*

Chemistry is broad enough to permit flexibility in its teaching, and college teachers exercise considerable freedom in methods and arrangements of topics in the effort to reach the objectives of their courses. There is no desire to impose greater uniformity on the secondary schools than now exists in the colleges. Therefore, the following list of topics for an AP course is intended to be a guide to the level and breadth of treatment expected rather than to be a syllabus.

The percentage after each major topic indicates the approximate proportion of questions on the examination that pertain to the topic. The examination is constructed using the percentages as guidelines for question distribution.

I. Structure of Matter (20%)

A. Atomic theory and atomic structure
   1. Evidence for the atomic theory
   2. Atomic masses; determination by chemical and physical means
   3. Atomic number and mass number; isotopes
   4. Electron energy levels: atomic spectra, quantum numbers, atomic orbitals
   5. Periodic relationships including, for example, atomic radii, ionization energies, electron affinities, oxidation states

B. Chemical bonding
   1. Binding forces
      a. Types: ionic, covalent, metallic, hydrogen bonding, van der Waals (including London dispersion forces)
      b. Relationships to states, structure, and properties of matter
      c. Polarity of bonds, electronegativities
   2. Molecular models
      a. Lewis structures
      b. Valence bond: hybridization of orbitals, resonance, sigma and pi bonds
      c. VSEPR
   3. Geometry of molecules and ions, structural isomerism of simple organic molecules and coordination complexes; dipole moments of molecules; relation of properties to structure

C. Nuclear chemistry: nuclear equations, half-lives, and radioactivity; chemical applications

II. States of Matter (20%)

A. Gases
   1. Laws of ideal gases
      a. Equation of state for an ideal gas
      b. Partial pressures
   2. Kinetic-molecular theory
      a. Interpretation of ideal gas laws on the basis of this theory
      b. Avogadro's hypothesis and the mole concept
      c. Dependence of kinetic energy of molecules on temperature
      d. Deviations from ideal gas laws

B. Liquids and solids
   1. Liquids and solids from the kinetic-molecular viewpoint
   2. Phase diagrams of one-component systems
   3. Changes of state, including critical points and triple points
   4. Structure of solids; lattice energies

C. Solutions
   1. Types of solutions and factors affecting solubility
   2. Methods of expressing concentration (The use of normalities is not tested.)
   3. Raoult's law and colligative properties (nonvolatile solutes); osmosis
   4. Non-ideal behavior (qualitative aspects)

III. Reactions (35–40%)

A. Reaction types
   1. Acid-base reactions; concepts of Arrhenius, Brønsted-Lowry, and Lewis; coordination complexes; amphoterism
   2. Precipitation reactions
   3. Oxidation-reduction reactions
      a. Oxidation number
      b. The role of the electron in oxidation-reduction
      c. Electrochemistry: electrolytic and galvanic cells; Faraday's laws; standard half-cell potentials; Nernst equation; prediction of the direction of redox reactions

B. Stoichiometry
   1. Ionic and molecular species present in chemical systems: net ionic equations
   2. Balancing of equations including those for redox reactions

3. Mass and volume relations with emphasis on the mole concept, including empirical formulas and limiting reactants

C. Equilibrium
   1. Concept of dynamic equilibrium, physical and chemical; Le Chatelier's principle; equilibrium constants
   2. Quantitative treatment
      a. Equilibrium constants for gaseous reactions: K_p, K_c
      b. Equilibrium constants for reactions in solution
         (1) Constants for acids and bases; pK; pH
         (2) Solubility product constants and their application to precipitation and the dissolution of slightly soluble compounds
         (3) Common ion effect; buffers; hydrolysis

D. Kinetics
   1. Concept of rate of reaction
   2. Use of experimental data and graphical analysis to determine reactant order, rate constants, and reaction rate laws
   3. Effect of temperature change on rates
   4. Energy of activation; the role of catalysts
   5. The relationship between the rate-determining step and a mechanism

E. Thermodynamics
   1. State functions
   2. First law: change in enthalpy; heat of formation; heat of reaction; Hess's law; heats of vaporization and fusion; calorimetry
   3. Second law: entropy; free energy of formation; free energy of reaction; dependence of change in free energy on enthalpy and entropy changes
   4. Relationship of change in free energy to equilibrium constants and electrode potentials

IV. Descriptive Chemistry (10–15%)

Knowledge of specific facts of chemistry is essential for an understanding of principles and concepts. These descriptive facts, including the chemistry involved in environmental and societal issues, should not be isolated from the principles being studied but should be taught throughout the course to illustrate and illuminate the principles. The following areas should be covered:

1. Chemical reactivity and products of chemical reactions
2. Relationships in the periodic table: horizontal, vertical, and diagonal with examples from alkali metals, alkaline earth metals, halogens, and the first series of transition elements
3. Introduction to organic chemistry: hydrocarbons and functional groups (structure, nomenclature, chemical properties). Physical and chemical properties of simple organic compounds should also be included as exemplary material for the study of other areas such as bonding, equilibria involving weak acids, kinetics, colligative properties, and stoichiometric determinations of empirical and molecular formulas.

V. Laboratory (5–10%)

The differences between college chemistry and the usual secondary school chemistry course are especially evident in the laboratory work. The AP Chemistry Examination includes some questions based on experiences and skills students acquire in the laboratory:

- making observations of chemical reactions and substances
- recording data
- calculating and interpreting results based on the quantitative data obtained
- communicating effectively the results of experimental work

For information on the requirements for an AP Chemistry laboratory program, the *Guide for the Recommended Laboratory Program* is included on pages 33-53 of this booklet. The Guide describes the general requirements for an AP Chemistry laboratory program and contains a list of recommended experiments. Also included in the Guide is a list of resources that AP Chemistry teachers should find helpful in developing a successful laboratory program.

Colleges have reported that some AP candidates, while doing well on the examination, have been at a serious disadvantage because of inadequate laboratory experience. Meaningful laboratory work is important in fulfilling the requirements of a college-level course of a laboratory science and in preparing a student for sophomore-level chemistry courses in college.

Because chemistry professors at some institutions ask to see a record of the laboratory work done by an AP student before making a decision about granting credit, placement, or both, in the chemistry program, students should keep reports of their laboratory work in such a fashion that the reports can be readily reviewed.

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 Examination

The AP Chemistry Examination is a 180-minute examination, divided into two parts. The first part (90 minutes) constitutes 45 percent of the final grade and consists of 75 multiple-choice questions with broad coverage of topics. Teachers should not try to prepare students to answer every question on a test of this kind. 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 test must be so comprehensive that no student should be expected to make a perfect or near-perfect score. Thought-provoking problems and questions based on fundamental ideas from chemistry are included.

The second part of the examination, which constitutes 55 percent of the final grade, is 90 minutes. For the first 40 minutes of this part, students will be permitted to use a calculator as they work on several comprehensive problems. Time will be called at 40 minutes, after which calculators must be put away for the remaining 50 minutes. During these last 50 minutes, students will answer a question requiring the determination of products of chemical reactions and several essay questions.

The student is allowed considerable choice among the questions included in the second part of the examination. The problems allow the student to demonstrate reasoning abilities by the application of chemical principles to problem solving. The question pertaining to descriptive chemistry in this section of the examination asks students to write ionic and molecular formulas for reactants and products of chemical reactions. The essays give the candidate an opportunity to demonstrate the ability to think clearly and to present ideas in a logical and coherent fashion.

Calculators and Equation Tables

The policy regarding the use of calculators on the AP Chemistry Examination 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 taking the section of the examination 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 Examination. 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 16-19 (#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 exceptions noted below) will be allowed only during the first 40 minutes of the free-response section of the examination. During this time, students will work on two problems, one that is required and one chosen from a set of two other problems. **Any programmable or graphing calculator may be used, and students will NOT be required to erase their calculator memories before or after the examination.** Students will not be allowed to move on to the last portion of the free-response section until time is called and all

*__Exceptions to calculator use.__ Although most calculators are permitted on the free-response section, it should be noted that they may not be shared with other students and that calculators with typewriter-style (qwerty) keyboards are not permitted.

calculators are put away. For the last 50 minutes of the examination, students will work, without calculators, on the remaining portion of the free-response section.

Tables containing equations commonly used in chemistry are printed on the green inserts provided with each examination for students to use when taking the free-response section. The equation tables are NOT permitted for use with the multiple-choice section of the examination. The equation tables are reprinted on pages 13-14 of this booklet. In general, the equations for each year's examination will be 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, since the equation tables will be provided with the examination, students will NOT be allowed to bring their own copies to the examination room.

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 grading 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 examination. 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 examination 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.

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

$$\Delta E = h\nu$$
$$c = \lambda \nu$$
$$\lambda = \frac{h}{mv}$$
$$p = mv$$
$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

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

EQUILIBRIUM

$$K_a = \frac{[H^+][A^-]}{[HA]}$$
$$K_b = \frac{[OH^-][HB^+]}{[B]}$$
$$K_w = [OH^-][H^+] = 1.0 \times 10^{-14} \text{ @ } 25°C$$
$$= K_a \times K_b$$
$$pH = -\log[H^+],\ pOH = -\log[OH^-]$$
$$14 = pH + pOH$$
$$pH = pK_a + \log\frac{[A^-]}{[HA]}$$
$$pOH = pK_b + \log\frac{[HB^+]}{[B]}$$
$$pK_a = -\log K_a,\ pK_b = -\log K_b$$
$$K_p = K_c(RT)^{\Delta n},$$
where Δn = moles product gas − moles reactant gas

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

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

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

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

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

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

Equilibrium Constants

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

THERMOCHEMISTRY

$$\Delta S° = \sum S° \text{ products} - \sum S° \text{ reactants}$$
$$\Delta H° = \sum \Delta H_f° \text{ products} - \sum \Delta H_f° \text{ reactants}$$
$$\Delta G° = \sum \Delta G_f° \text{ products} - \sum \Delta G_f° \text{ reactants}$$
$$\Delta G° = \Delta H° - T\Delta S°$$
$$= -RT \ln K = -2.303\, RT \log K$$
$$= -n \mathcal{F} E°$$
$$\Delta G = \Delta G° + RT \ln Q = \Delta G° + 2.303\, RT \log Q$$
$$q = mc\Delta T$$
$$C_p = \frac{\Delta H}{\Delta T}$$

$S°$ = 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
1 faraday $\mathcal{F}$ = 96,500 coulombs

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

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

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

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

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

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

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

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

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

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

$$\pi = \frac{nRT}{V}i$$

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
$\mathbf{M}$ = molar mass
π = osmotic pressure
i = van't Hoff factor
K_f = molal freezing-point depression constant
K_b = molal boiling-point elevation constant
Q = reaction quotient
I = current (amperes)
q = charge (coulombs)
t = time (seconds)
E° = standard reduction potential
K = equilibrium constant

Gas constant, $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
$= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$
$= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$
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 = $0.512 \text{ K kg mol}^{-1}$
STP = 0.000°C and 1.000 atm
Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

OXIDATION-REDUCTION; ELECTROCHEMISTRY

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

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

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

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

Multiple-Choice Questions

The following multiple-choice questions provide a representative subset of those used in previous AP Examinations in Chemistry. There are two types of multiple-choice questions on the examination. The first type of question 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.

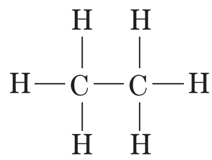
(A) Lithium
(B) Carbon
(C) Nitrogen
(D) Oxygen
(E) Fluorine

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 not 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) $SO_3^{2-}(aq) \rightarrow SO_4^{2-}(aq)$

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

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) $HCN(aq) + C_2H_3O_2^-(aq) \rightleftarrows HC_2H_3O_2(aq) + CN^-(aq)$

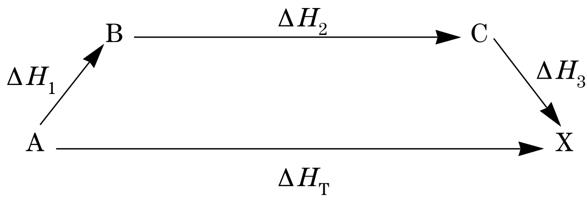
Experiment	*Initial* [X] *(mol L^{-1})*	*Initial* [Y] *(mol L^{-1})*	*Initial Rate of Formulation of* Z *(mol L^{-1} min^{-1})*
1	0.10	0.30	4.0×10^{-4}
2	0.20	0.60	1.6×10^{-3}
3	0.20	0.30	4.0×10^{-4}

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

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

$$A \rightarrow X$$

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) $CH_3CH_2CH_2OH$, l-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

29. The table below summarizes the reactions of a certain unknown solution when treated with bases.

		Results	
Sample	*Reagent*	*Limited Amount of Reagent*	*Excess Reagent*
I	NaOH (*aq*)	White precipitate	Precipitate dissolves
II	NH_3(*aq*)	White precipitate	White precipitate

Which of the following metallic ions could be present in the unknown solution?

(A) Ca^{2+} (*aq*) (B) Zn^{2+} (*aq*) (C) Ni^{2+} (*aq*) (D) Al^{3+} (*aq*) (E) Ag^{+} (*aq*)

Essay Questions

Section II of the 1998 AP Chemistry Examination is reproduced here. Students are provided with a periodic table, a table of standard reduction potentials, and a table containing various equations and constants. Please note that in 2000 the format of Section II will differ from the format that follows.

Part A

Time—40 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

Question 1 (Required)
(20 percent)

1. Solve the following problem related to the solubility equilibria of some metal hydroxides in aqueous solution.

   (a) The solubility of $Cu(OH)_2(s)$ is 1.72×10^{-6} gram per 100. milliliters of solution at 25°C.
   - (i) Write the balanced chemical equation for the dissociation of $Cu(OH)_2\ (s)$ in aqueous solution.
   - (ii) Calculate the solubility (in moles per liter) of $Cu(OH)_2$ at 25°C.
   - (iii) Calculate the value of the solubility-product constant, K_{sp}, for $Cu(OH)_2$ at 25°C.

   (b) The value of the solubility-product constant, K_{sp} for $Zn(OH)_2$ is 7.7×10^{-17} at 25°C.
   - (i) Calculate the solubility (in moles per liter) of $Zn(OH)_2$ at 25°C in a solution with a pH of 9.35.
   - (ii) At 25°C, 50.0 milliliters of 0.100-molar $Zn(NO_3)_2$ is mixed with 50.0 milliliters of 0.300-molar NaOH. Calculate the molar concentration of $Zn^{2+}(aq)$ in the resulting solution once equilibrium has been established. Assume that volumes are additive.

Question 2 or 3 (Choose either one.)
(20 percent)

Solve EITHER Problem 2 OR Problem 3. (Only one of these problems will be scored. If you start both problems, be sure to cross out the one you do not want scored.)

2. An unknown compound contains only the three elements C, H, and O. A pure sample of the compound is analyzed and found to be 65.60 percent C and 9.44 percent H by mass.

   (a) Determine the empirical formula of the compound.

   (b) A solution of 1.570 grams of the compound in 16.08 grams of camphor is observed to freeze at a temperature 15.2 Celsius degrees below the normal freezing point of pure camphor. Determine the molar mass and apparent molecular formula of the compound. (The molal freezing-point depression constant, K_f, for camphor is $40.0 \text{ kg} \cdot \text{K} \cdot \text{mol}^{-1}$.)

   (c) When 1.570 grams of the compound is vaporized at 300°C and 1.00 atmosphere, the gas occupies a volume of 577 milliliters. What is the molar mass of the compound based on this result?

   (d) Briefly describe what occurs in solution that accounts for the difference between the results obtained in parts (b) and (c).

3. $$C_6H_5OH(s) + 7\ O_2\ (g) \rightarrow 6\ CO_2\ (g) + 3\ H_2O\ (l)$$

When a 2.000-gram sample of pure phenol, $C_6H_5OH(s)$, is completely burned according to the equation above, 64.98 kilojoules of heat is released. Use the information in the table below to answer the questions that follow.

Substance	Standard Heat of Formation, ΔH_f°, at 25°C (kJ/mol)	Absolute Entropy, S°, at 25°C (J/mol · K)
C (graphite)	0.00	5.69
$CO_2\ (g)$	–393.5	213.6
$H_2\ (g)$	0.00	130.6
$H_2O\ (l)$	–285.85	69.91
$O_2\ (g)$	0.00	205.0
$C_6H_5OH\ (s)$	?	144.0

(a) Calculate the molar heat of combustion of phenol in kilojoules per mole at 25°C.

(b) Calculate the standard heat of formation, ΔH_f°, of phenol in kilojoules per mole at 25°C.

(c) Calculate the value of the standard free-energy change, ΔG°, for the combustion of phenol at 25°C.

(d) If the volume of the combustion container is 10.0 liters, calculate the final pressure in the container when the temperature is changed to 110.°C. (Assume no oxygen remains unreacted and that all products are gaseous.)

Part B

Time—50 minutes

NO CALCULATORS MAY BE USED WITH PART B.

Question 4 (Required)
(15 percent)

4. Answer FIVE of the eight choices in this problem. (Answers to more than five choices will not be scored.)

   Write the formulas to show the reactants and the products for FIVE of the following chemical reactions. Each of the reactions occurs in aqueous solution unless otherwise indicated. Represent substances in solution as ions if the substance is extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. In all cases a reaction occurs. You need not balance the equations.

   <u>Example:</u> A strip of magnesium is added to a solution of silver nitrate.

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

(a) Solutions of tin(II) chloride and iron(III) chloride are mixed.

(b) Solutions of cobalt(II) nitrate and sodium hydroxide are mixed.

(c) Ethene gas is burned in air.

(d) Equal volumes of equimolar solutions of phosphoric acid and potassium hydroxide are mixed.

(e) Solid calcium sulfite is heated in a vacuum.

(f) Excess hydrochloric acid is added to a solution of diammine-silver(I) nitrate.

(g) Solid sodium oxide is added to distilled water.

(h) A strip of zinc is added to a solution of 6.0-molar hydrobromic acid.

Question 5 (Required)
(15 percent)

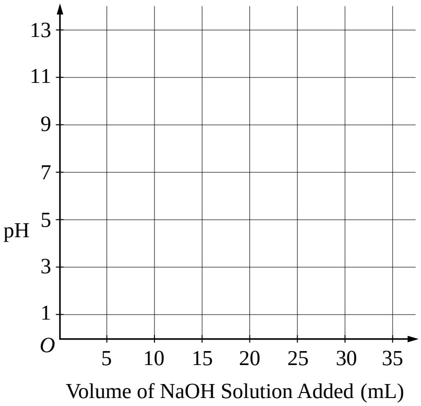
5. An approximately 0.1-molar solution of NaOH is to be standardized by titration. Assume that the following materials are available.

- Clean, dry 50 mL buret
- 250 mL Erlenmeyer flask
- Wash bottle filled with distilled water
- Analytical balance
- Phenolphthalein indicator solution
- Potassium hydrogen phthalate, KHP, a pure solid monoprotic acid (to be used as the primary standard)

(a) Briefly describe the steps you would take, using the materials listed above, to standardize the NaOH solution.

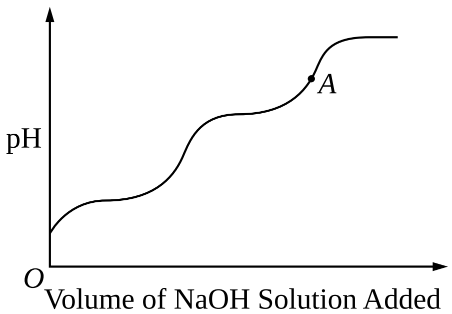
(b) Describe (i.e., set up) the calculations necessary to determine the concentration of the NaOH solution.

(c) After the NaOH solution has been standardized, it is used to titrate a weak monoprotic acid, HX. The equivalence point is reached when 25.0 mL of NaOH solution has been added. In the space provided at the right, sketch the titration curve, showing the pH changes that occur as the volume of NaOH solution added increases from 0 to 35.0 mL. Clearly label the equivalence point on the curve.



(d) Describe how the value of the acid-dissociation constant, K_a, for the weak acid HX could be determined from the titration curve in part (c).

(e) The graph below shows the results obtained by titrating a different weak acid, H_2Y, with the standardized NaOH solution. Identify the negative ion that is present in the highest concentration at the point in the titration represented by the letter *A* on the curve.



Questions 6-9 (Choose any two.)
(30 percent)

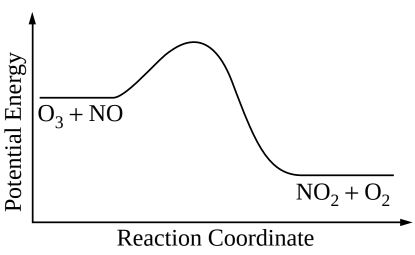
6. Answer the following questions regarding the kinetics of chemical reactions.

(a) The diagram at right shows the energy pathway for the reaction $O_3 + NO \rightarrow NO_2 + O_2$.

Clearly label the following directly on the diagram.

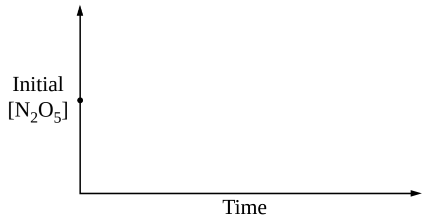
(i) The activation energy (E_a) for the forward reaction

(ii) The enthalpy change (ΔH) for the reaction



(b) The reaction $2\ N_2O_5 \rightarrow 4\ NO_2 + O_2$ is first order with respect to N_2O_5.

(i) Using the axes at right, complete the graph that represents the change in $[N_2O_5]$ over time as the reaction proceeds.

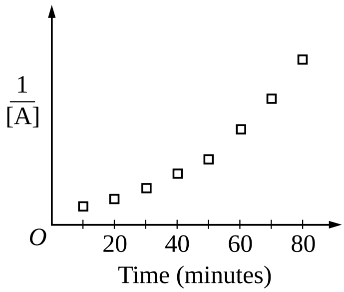


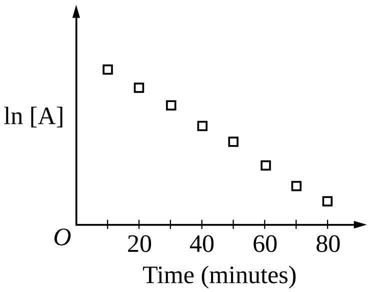
(ii) Describe how the graph in (i) could be used to find the reaction rate at a given time, t.

(iii) Considering the rate law and the graph in (i), describe how the value of the rate constant, k, could be determined.

(iv) If more N_2O_5 were added to the reaction mixture at constant temperature, what would be the effect on the rate constant, k? Explain.

(c) Data for the chemical reaction $2\ A \rightarrow B + C$ were collected by measuring the concentration of A at 10-minute intervals for 80 minutes. The following graphs were generated from analysis of the data.





Use the information in the graphs above to answer the following.

(i) Write the rate-law expression for the reaction. Justify your answer.

(ii) Describe how to determine the value of the rate constant for the reaction.

7. $C(s) + H_2O(g) \rightleftarrows CO(g) + H_2(g) \qquad \Delta H = +131\text{ kJ}$

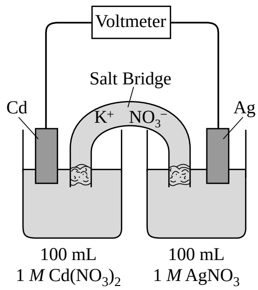
A rigid container holds a mixture of graphite pellets ($C(s)$), $H_2O(g)$, $CO(g)$, and $H_2(g)$ at equilibrium. State whether the number of moles of $CO(g)$ in the container will <u>increase</u>, <u>decrease</u>, or <u>remain the same</u> after each of the following disturbances is applied to the original mixture. For each case, assume that all other variables remain constant except for the given disturbance. Explain each answer with a short statement.

(a) Additional $H_2(g)$ is added to the equilibrium mixture at constant volume.

(b) The temperature of the equilibrium mixture is increased at constant volume.

(c) The volume of the container is decreased at constant temperature.

(d) The graphite pellets are pulverized.



8. Answer the following questions regarding the electrochemical cell shown above.

   (a) Write the balanced net-ionic equation for the spontaneous reaction that occurs as the cell operates, and determine the cell voltage.

   (b) In which direction do anions flow in the salt bridge as the cell operates? Justify your answer.

   (c) If 10.0 mL of 3.0-molar $AgNO_3$ solution is added to the half-cell on the right, what will happen to the cell voltage? Explain.

   (d) If 1.0 gram of solid NaCl is added to each half-cell, what will happen to the cell voltage? Explain.

   (e) If 20.0 mL of distilled water is added to both half-cells, the cell voltage decreases. Explain.

9. Answer each of the following using appropriate chemical principles.

   (a) Why does it take longer to cook an egg in boiling water at high altitude than it does at sea level?

   (b) When NH_3 gas is bubbled into an aqueous solution of $CuCl_2$, a precipitate forms initially. On further bubbling, the precipitate disappears. Explain these two observations.

   (c) Dimethyl ether, $H_3C—O—CH_3$ is not very soluble in water. Draw a structural isomer of dimethyl ether that is much more soluble in water and explain the basis of its increased water solubility.

   (d) Identify a chemical species that is

      (i) capable of oxidizing Cl^- (*aq*) under standard conditions

      (ii) capable of reducing Cl_2 (*aq*) under standard conditions.

   In each case, justify your choice.

Guide for the Recommended Laboratory Program for Advanced Placement Chemistry

The authors of this laboratory guide are the following former and current members of the AP Chemistry Development Committee.

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The College Board gratefully acknowledges their contribution.

Guide Outline

Introduction

General Requirements for an AP Chemistry Laboratory Program

A. School Resources
B. Teacher Preparation Time
C. Teacher Professional Development

Skills and Procedures To Be Learned and Reinforced in the Laboratory

A. Laboratory Program Goals
B. Laboratory Performance Skills
    1. Physical Manipulations
    2. Processes and Procedures
    3. Observations and Data Manipulation
    4. Communication, Group Collaboration, and the Laboratory Record
C. Laboratory Safety

> *"I hear and I forget. I see and I remember. I do, and I understand."*
> Old Chinese Proverb

> *"A fool . . . never tried an experiment in his life."*
> Erasmus Darwin, 1792

Introduction

Colleges and universities have a laboratory associated with their first-year general chemistry course. If an AP Chemistry course is to be the equivalent of such a course in quality and sophistication, students need to engage in the process of doing laboratory chemistry as well as writing about chemistry and doing quantitative calculations in chemistry problems. The AP Chemistry Development Committee has produced this guide to help teachers and administrators understand the role that laboratory work should play in every AP Chemistry course. This information supplements the guidance provided in the course syllabus, which should also be consulted for the most up-to-date information on expectations.

This document does not attempt to provide detailed instructions for experiments, as Committee members believe that these are readily available in a number of standard laboratory manuals. Furthermore, it is important that the AP Chemistry laboratory program be adapted to local conditions, even while it aims to offer the students a well-rounded experience with experimental chemistry.

Models showing how several instructors in widely different circumstances have tackled the problems inherent in establishing a high-quality program in AP Chemistry, including laboratory work, are described in considerable detail in the *Teacher's Guide in AP Chemistry*, which is published by the College Board.

General Requirements for an AP Chemistry Laboratory Program

The school faculty and administration must make an appropriate commitment for successful implementation of an AP Chemistry course that is designed to be the equivalent of the first-year college course in laboratory chemistry. There are a number of facets to this commitment, including facilities, teacher preparation and training, scheduling, and supplies that must be present for a quality program. A brief review of these items is included in this section. Teachers and administrators must work together to achieve these goals.

A. School Resources

1. A separate operating and capital budget should be established with the understanding that the per pupil expenditures for this course will be substantially higher than those for regular high school laboratory science courses. Adequate laboratory facilities should be provided so that each student has a work space where equipment and materials can be left overnight if necessary. Sufficient laboratory glassware for the anticipated enrollment and appropriate instruments (sensitive balances, spectrophotometers, and pH meters) should be provided.
2. Students in AP Chemistry should have access to computers with software appropriate for processing laboratory data and writing reports.
3. A laboratory assistant should be provided in the form of a paid or unpaid aide. Parent volunteers, if well organized, may be able to help fill such a role.
4. Counseling and guidance personnel should be thoroughly briefed as to the nature of the program and the need to have students succeed in the course. Full attention must be given to mechanisms that identify potentially successful candidates and avoid inappropriate placement of students.
5. Flexible or modular scheduling must be implemented in order to meet the time requirements identified in the course outline. Some schools are able to assign daily double periods so that laboratory and quantitative problem-solving skills may be fully developed. At the very least, a weekly extended laboratory period is needed. *It is not possible to complete high-quality AP laboratory work within standard 45- to 50-minute periods.*

B. Teacher Preparation Time

Because of the nature of the AP Chemistry course, the teacher needs extra time to prepare for laboratory work. Therefore, adequate time must be allotted during the academic year for teacher planning and testing of laboratory experiments.

In the first year of starting an AP Chemistry course, one month of summer time and one additional period each week are also necessary for course preparation work. In subsequent years, an AP Chemistry teacher routinely requires one extra period each week to devote to course preparation.

C. Teacher Professional Development

AP Chemistry teachers need to stay abreast of current developments in teaching college chemistry. This is done through contacts with college faculty and with high school teacher colleagues. Schools should offer stipends and travel support to enable their teachers to attend workshops and conferences. An adequate budget should be established at the school to support professional development of the AP Chemistry teacher. The following are examples of such opportunities.

1. One- or two-week AP summer institutes (some supported by the College Board) are offered in several locations.
2. One-day AP conferences are sponsored by College Board regional offices. At these, presentations are made by experienced AP or college-level teachers, many of whom have been involved as faculty consultants at AP Readings or as members of the Development Committee.
3. AP institutes covering several disciplines are offered as two- or three-day sessions during the school year. These are also organized by College Board regional offices and are held at hotels or universities.
4. Additional opportunities are often provided by local colleges or universities, or by local sections of the American Chemical Society. These can be in the form of one-day workshops, weekend retreats, or summer courses. All offer excellent networking possibilities for AP Chemistry teachers, who can exchange ideas with their colleagues and build long-term support relationships.

Skills and Procedures To Be Learned and Reinforced in the Laboratory

> *"When a fact appears opposed to a long train of deductions it invariably proves to be capable of bearing some other interpretation."*
>
> Sherlock Holmes in *A Study in Scarlet*.

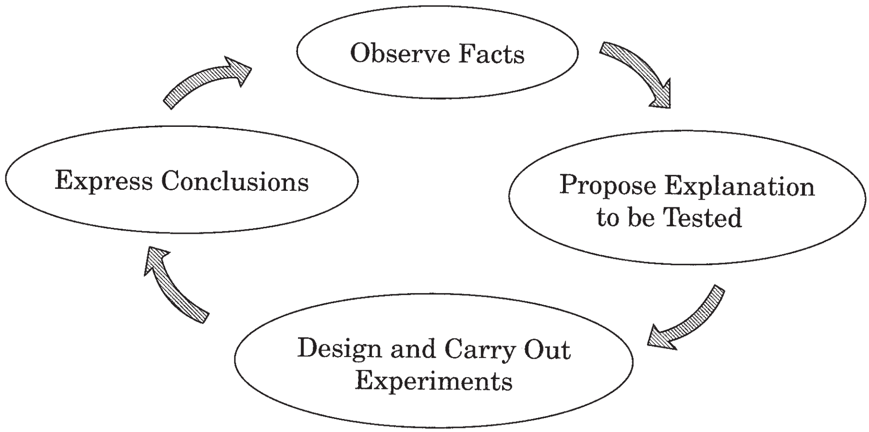
A. Laboratory Program Goals

The chemistry laboratory is the place where students learn about the behavior of matter by firsthand observation… to see what actually happens when the " stuff " that makes up the world is "prodded" and " poked." The observations students make may be in marked contrast to preconceived notions of what "should happen" according to textbooks or simplistic theoretical models. The laboratory is the place to learn the difference between observations/recorded data (i.e., facts) and the ideas, inferences, explanations, models (i.e., theories) that may be used to interpret them but are often incomplete or never actually observed.

The laboratory program that is adopted should challenge every student's ability to:

- think analytically and to reduce problems to identifiable, answerable questions;
- understand problems expressed as experimental questions;
- design and carry out experiments that answer questions;
- manipulate data acquired during an experiment—perhaps even to guide progress;
- make conclusions and evaluate the quality and validity of such conclusions;
- propose further questions for study; and
- communicate accurately and meaningfully about observations and conclusions.

The program of laboratory investigations should be seen as a cyclic continuum of inquiry rather than a linear sequence of steps with a beginning and an end.



Toward this goal, the ideal program should not only allow students to gain experience with traditional laboratory exercises (such as those suggested later) but also provide opportunities for students to carry out novel investigations.

B. Laboratory Performance Skills

"To play a violin, one needs to know how to handle it properly. To do a meaningful experiment, one must mix and measure just as properly."

Sienko, Plane, and Marcus, 1984

1. Physical Manipulations

Students must learn the skills necessary to use ordinary equipment such as:

- beakers, flasks, test tubes, crucibles, evaporating dishes, watch glasses, burners, plastic and glass tubing, stoppers, valves, spot plates, funnels, reagent bottles, wash bottles, and droppers;

and measuring equipment, including:

- balances (single pan, double pan, triple beam), thermometers (°C), barometers, graduated cylinders, burets, volumetric pipets, graduated pipets, volumetric flasks, ammeters and voltmeters, pH meters, and spectrophotometers.

2. Processes and Procedures

Familiarity, involving more than a single day's experience, is important with such general types of chemical laboratory work as the following:

- synthesis of compounds (solid and gas)
- separations (precipitation and filtration, dehydration, centrifugation, distillation, chromatography)
- observing and recording phase changes (solid - liquid - gas)
- titration using indicators and meters
- spectrophotometry/colorimetry
- devising and utilizing a scheme for qualitative analysis of ions in solution
- gravimetric analysis

Some colleges have laboratory practical examinations in which students must perform certain operations accurately within time constraints. Even though this is not part of the AP Chemistry Examination, such exercises are useful in providing students with goals for the development and practice of their laboratory skills.

3. Observations and Data Manipulation

Students must practice the art of making careful observations and of recording accurately what they observe. Too frequently students confuse *what they see* with *what they think they are supposed to see.* They should be encouraged to be accurate reporters even when this seems to conflict with what the textbook or laboratory procedure has led them to expect. Several great discoveries were made this way (e.g., penicillin and Teflon).

Interpretation of proper observations is also important. Students should be familiar with finding evidence of chemical change (color change, precipitate formation, temperature change, gas evolution, etc.) and its absence (for example, in the identification of spectator ions).

Students should know how to make and interpret quantitative measurements correctly. This includes knowing which piece of apparatus is appropriate. For example, a student should be able to select the correct glassware to dispense *about* 50 mL, and the best glassware to dispense *precisely* 10.00 mL of a solution.

Students need a great deal of practice in recording and reporting both qualitative and quantitative information. They should be encouraged to do this properly and at the time that the information is obtained. Often this means anticipating the need to prepare a table in which to record the information to be gathered, or a graph on which to plot it. For example, when graphs are prepared during the experiment rather than at some later time, discordant data can often be detected immediately and measurements repeated with little lost time. This is preferable to finding out later that most of the time spent on the experiment was wasted because of some error or misreading.

Students should be given ample opportunity to evaluate their own data, to do their own calculations, and to puzzle over their own errors. They should learn to distinguish between mistakes (blunders) and scientific (experimental) errors. In the latter case, they should also be able to distinguish between systematic and random errors and know how to evaluate their final conclusions in the context of experimental reliability. Even when time does not permit repetition of experiments, students should be asked to comment on how they could have improved their measurements in order to arrive at a more precise conclusion. If extensive computational assistance is available (e.g., a spreadsheet computer program), students should be using it, but they should have full understanding of the operations involved and not just blindly enter numbers to get a "magic" result.

4. Communication, Group Collaboration, and the Laboratory Record

Laboratory work is an excellent way to help students develop and practice communication skills. Success in subsequent work in chemistry depends heavily on an ability to communicate about chemical observations, ideas, and conclusions. Students must learn to recognize that claiming a knowledge and understanding of chemistry is relatively useless unless they can communicate this knowledge effectively to others.

By working together in a truly collaborative manner to plan and carry out experiments, students learn appropriate oral communication skills as well as how to build social team relationships important to their future scientific work. They must be encouraged to take full individual responsibility for the success of the collaboration and not be a sleeping partner ready to blame the rest of the team for failure. Properly operating teams can assist the instructor greatly by taking over much of the responsibility for preparation and selection of materials, for assuring safe manipulations, and for cleaning up the laboratory. Effective teams can accomplish more in a given time by working in parallel.

Students must learn how to keep proper records of their experimental work. Even when teams perform experiments, each student should be responsible for making his or her own record of the data obtained. In group work, this ideally leads to double or triple checking of all actions and results, which helps to avoid mistakes and reinforces the idea that the entire team is responsible for the overall experiment. Student laboratory records should form part of the ongoing assessment and evaluation for the course.

If students are required to keep proper records of all experimental work done in the course, they will end the year with a document that is a source of pride and that demonstrates the growth of their skills. *This record is an important document that may be requested by the Chemistry Department at a college or university when a decision is needed regarding credit and/or placement in more advanced chemistry courses.*

C. Laboratory Safety

The conditions under which AP Chemistry courses are offered vary widely as to facilities and equipment. This is also true for colleges and universities offering general chemistry courses. However, it is important that certain concerns regarding laboratory safety be addressed in all programs.

This is important not only for student and instructor safety at the time but also so that students who enter more advanced courses in chemistry have a considerable and expected familiarity with safe laboratory practices.

1. All facilities should conform to federal, state, and local laws and guidelines as they pertain to the safety of students and instructors.
2. Teachers with a limited background in chemistry should receive additional training specifically related to laboratory safety for chemistry laboratories before beginning an assignment in an AP Chemistry course.
3. Laboratory experiments and demonstrations should not be carried out by AP Chemistry students if they could expose the students to risks or hazards that are inappropriate for learning in the instructional sequence (e.g., explosion experiments that do not have any learning objective).
4. Students should be fully informed of potential laboratory hazards relating to chemicals and apparatus before performing specific experiments. If possible, students themselves should research needed safety information in advance when there is access to such information in a library or at a local college.
5. Storage and disposal of hazardous chemicals must always be done in accordance with local regulations and policies. As far as possible, the students as well as the instructor should know what these regulations are.

Basic laboratory safety instruction for students should be an integral part of each laboratory experience. Topics that should be covered include:

- simple first aid for cuts, thermal and chemical burns;
- use of safety goggles, eye washes, body showers, fire blankets, and fire extinguishers;
- safe handling of glassware, hot plates, burners and other heating devices, and electrical equipment;
- proper interpretation of Material Safety Data Sheets (MSDS) and hazard warning labels; and
- proper use and reuse practices (including proper labeling of interim containers) for reagent bottles.

A successful AP Chemistry laboratory program will instill in each student a true, lifelong "safety sense" that will ensure his or her safe transition into more advanced laboratory work in college or university laboratories or into the industrial workplace environment.

Microscale Experiments—An Answer to Time, Resource, and Safety Concerns?

One important change in chemistry laboratory instruction in recent years has been the introduction of microscale experiments. While the initial goal in this development may have been to improve safety by reducing the amounts of hazardous materials handled, several other benefits have been realized. These include:

- decreased cost of chemicals acquisition and disposal;
- reduced storage space requirements and safer storage;
- less need for elaborate laboratory facilities in schools;
- greater care needed by students to obtain and observe results;
- shorter experiment times as well as easier and faster clean-up; and
- ability to carry out some experiments that were once restricted to demonstrations because of their hazards in macroscale.

Some of these benefits are of particular interest to the AP Chemistry teacher because less time, poorer facilities, and fewer resources for laboratory work are available in high schools than in colleges and universities. The time and resources saved by using microscale can be used for more trials or for additional experiments, thus enabling students to complete a more meaningful laboratory program than might be possible with only macroscale techniques.

The techniques employed and the supplies needed for microscale experiments are described in several of the laboratory manuals that are listed in the resources section below. Typically, these experiments are carried out using plastic pipets and well trays, available at low cost from most laboratory supply houses. Some materials can be adapted from or replaced by items available at commercial restaurant supply and discount warehouses.

AP Chemistry teachers are encouraged to exchange information regarding effective microscale and macroscale laboratory experiments. This can readily be done through local AP workshops. Teachers should contact their regional College Board office to find out about such workshops. Also, it is strongly suggested that teachers contact local college or university chemistry departments and ask about their laboratory programs and their use of microscale techniques in general chemistry courses. The topic of "microscale laboratories" would make an ideal subject for a conference of chemistry instructors that could be organized by a local division of the American Chemical Society or other chemistry or science teacher's association. A regular feature on **The Microscale Laboratory** is included in the *Journal of Chemical Education.*

Many of the recommended experiments described in the following section are suitable for AP Chemistry in a microscale version.

Recommended Experiments

With the introduction in 1999 of a required laboratory-based question on the free-response section of the AP Chemistry Exam, the inclusion of appropriate experiments into each AP Chemistry course is increasingly important. Past studies have shown that student scores on the AP Chemistry Exam show a positive correlation with the time spent in the laboratory. This correlation is expected to be even stronger now that a question concerned with laboratory experiences is included on the examination each year.

It is unlikely that every student will complete all of the 22 laboratory experiments below while enrolled in an AP Chemistry course. Therefore, when planning a laboratory program, it may be useful to consider the experiments in various ways. For example, they might be grouped according to the skills and techniques that the experiments require; e.g. experiments 6, 7, 8, 11 and 19 are all related to titrations. Alternatively, they might be divided on the basis of the chemical concepts that they explore and reinforce; e.g. experiments 8, 20 and 21 all relate to oxidation-reduction and electrochemistry. The major consideration when selecting experiments should be to provide students with the broadest laboratory experience possible.

1. Determination of the formula of a compound

   Teacher preparation time: 2 hours
   Student completion time: 1.5 hours
   Equipment: crucible and cover, tongs, analytical balance, support stand, triangle crucible support, burner

2. Determination of the percentage of water in a hydrate

   Teacher preparation time: 2 hours
   Student completion time: 1 hour
   Equipment: crucible and cover, tongs, test tube, analytical balance, support stand, triangle crucible support, wire gauze, burner

3. Determination of molar mass by vapor density

   Teacher preparation time: 2 hours
   Student completion time: 1.5 hours
   Equipment: barometer, beaker, Erlenmeyer flask, graduated cylinder, clamp, analytical balance, support stand

4. Determination of molar mass by freezing-point depression

   Teacher preparation time: 1 hour
   Student completion time: 2 hours
   Equipment: test tube, thermometer, pipet, beaker, stirrer, stop-watch, ice

5. Determination of the molar volume of a gas

   Teacher preparation time: 1.5 hours
   Student completion time: 2 hours
   Equipment: barometer, beaker, Erlenmeyer flask, test tubes, graduated cylinder, clamp, analytical balance, thermometer, rubber tubing

6. Standardization of a solution using a primary standard

   Teacher preparation time: 1 hour
   Student completion time: 2 hours
   Equipment: pipet, buret, Erlenmeyer flasks, volumetric flask, wash bottle, analytical balance, drying oven, desiccator, support stand, pH meter

7. Determination of concentration by acid-base titration, including a weak acid or weak base

   Teacher preparation time: 1.5 hours
   Student completion time: 2 hours
   Equipment: pipet, buret, Erlenmeyer flasks, wash bottle, analytical balance, drying oven, desiccator, support stand and clamp, pH meter

8. Determination of concentration by oxidation-reduction titration

   Teacher preparation time: 1.5 hours
   Student completion time: 2 hours
   Equipment: pipet, buret, Erlenmeyer flasks, wash bottle, analytical balance, drying oven, desiccator, support stand and clamp, pH meter as millivoltmeter

9. Determination of mass and mole relationship in a chemical reaction

   Teacher preparation time: 1 hour
   Student completion time: 2 hours
   Equipment: beaker, Erlenmeyer flask, graduated cylinder, hot plate, desiccator, analytical balance

10. Determination of the equilibrium constant for a chemical reaction

    Teacher preparation time: 1.5 hours
    Student completion time: 2 hours
    Equipment: pipet, test tubes and/or cuvettes, volumetric flask, analytical balance, spectrophotometer (Spec 20 or 21)

11. Determination of appropriate indicators for various acid-base titrations; pH determination

    Teacher preparation time: 2 hours
    Student completion time: 2 hours
    Equipment: pipet, Erlenmeyer flasks, graduated cylinder, volumetric flask, analytical balance, pH meter

12. Determination of the rate of a reaction and its order

    Teacher preparation time: 2 hours
    Student completion time: 2 hours
    Equipment: pipet, buret, Erlenmeyer flasks, graduated cylinder or gas measuring tubes, stopwatch, thermometer, analytical balance, support stand and clamp

13. Determination of enthalpy change associated with a reaction

    Teacher preparation time: 0.5 hours
    Student completion time: 2 hours
    Equipment: calorimeter (can be polystyrene cup), graduated cylinder, thermometer, analytical balance

14. Separation and qualitative analysis of cations and anions

    Teacher preparation time: 2–4 hours
    Student completion time: 3+ hours
    Equipment: test tubes, beaker, evaporating dish, funnel, watch glass, mortar and pestle, centrifuge, Pt or Ni test wire

15. Synthesis of a coordination compound and its chemical analysis

    Teacher preparation time: 2 hours
    Student completion time: 2+ hours
    Equipment: beaker, Erlenmeyer flask, evaporating dish, volumetric flask, pipet, analytical balance, test tubes/cuvettes, spectrophotometer

16. Analytical gravimetric determination

    Teacher preparation time: 1 hour
    Student completion time: 1.5 hours
    Equipment: beakers, crucible and cover, funnel, desiccator, drying oven, Meker burner, analytical balance, support stand and crucible support triangle

17. Colorimetric or spectrophotometric analysis

    Teacher preparation time: 1 hour
    Student completion time: 2 hours
    Equipment: pipet, buret, test tubes and/or cuvettes, spectrophotometer, buret support stand

18. Separation by chromatography

    Teacher preparation time: 1 hour
    Student completion time: 2 hours
    Equipment: test tubes, pipet, beaker, capillary tubes or open tubes or burets, ion exchange resin or silica gel (or filter paper strips, with heat lamp or blow dryer)

19. Preparation and properties of buffer solutions

    Teacher preparation time: 1 hour
    Student completion time: 1.5 hours
    Equipment: pipet, beaker, volumetric flask, pH meter

20. Determination of electrochemical series

    Teacher preparation time: 1 hour
    Student completion time: 1 hour
    Equipment: test tubes and holder rack, beakers, graduated cylinder, forceps

21. Measurements using electrochemical cells and electroplating

    Teacher preparation time: 1.5 hours
    Student completion time: 1.5 hours
    Equipment: test tubes, beaker, filter flasks, filter crucibles and adapters, electrodes, voltmeter, power supply (battery)

22. Synthesis, purification, and analysis of an organic compound

    Teacher preparation time: 0.5 hours
    Student completion time: 2+ hours
    Equipment: Erlenmeyer flask, water bath, thermometer, burner, filter flasks, evaporating dish (drying oven), analytical balance, burets, support stand, capillary tubes

Resources

> *"You will find it a very good practice to always verify your references, sir!"*
>
> Routh (1755–1854)

This listing is not meant to be exhaustive, but it represents suggestions from the authors for items that may be helpful to teachers beginning or adapting laboratory programs for AP Chemistry. Most general chemistry textbook publishers publish a laboratory manual keyed to their textbook. No attempt is made to list these here. *No endorsement of any program or publication is implied by this listing.*

A. General

Mullins, J., ed. *Teacher's Guide to Advanced Placement Courses in Chemistry.* New York: College Entrance Examination Board, 1994.

Sterenfeld, A.A., and B. G. Segal, eds. *Teacher's Guide to Advanced Placement Courses in Chemistry.* New York: College Entrance Examination Board, 1989.

Gardner, M. *Laboratory Assessment Builds Success.* Berkeley, CA: Institute for Chemical Education at Lawrence Hall of Science. A model set of activities for high school chemistry focusing on integrating laboratory with learning and assessment in chemistry. Contains several experiments suitable for AP.

Dodd, J. S., ed. *The ACS Style Guide.* Washington, DC: American Chemical Society, 1986. Sections on word usage and table construction are especially useful.

B. Laboratory Manuals

Most laboratory manuals have associated instructor's guides or instructor's versions that provide invaluable help in preparing equipment and solutions. Most contain prelaboratory exercises for each experiment and special sections on safety, how to write laboratory reports, and general techniques for using apparatus. Each publisher of a textbook in general chemistry markets an associated laboratory manual. Many are ring bound to lie flat, or punched to be torn apart and inserted into a ring binder.

Abraham, M. R., and M. J. Pavelich. *Inquiries into Chemistry*, 2nd ed. Prospect Heights, IL.: Waveland Press, 1991. Has some open-ended experiments to challenge students and guided inquiry experiments to introduce concepts. Mostly macroscale, but some microscale experiments.

Allen, C. B., S. C. Bunce, and J. W. Zubrick. *Project ChemLab*. Washington, DC: American Chemical Society, Division of Chemical Education, 1988. An annotated list of all experiments in *Journal of Chemical Education* from 1957 to 1984. Also available on disk from JCE Software. Includes general chemistry and more advanced experiments.

Baker, A. D. *Laboratory Manual to Accompany Chemistry by Radel and Navidi*. St. Paul, MN: West Publishing Co., 1990. Contains 38 experiments, 13 special technique sections, and 4 study assignments. Combines traditional experiments with some from the British Nuffield Science Project with a balance of basic technique with concept familiarization experiments.

Bishop, C. B. et al. *Experiments for General Chemistry*, 2nd ed. Orlando, FL: Saunders College Pub., 1992. Contains 32 experiments, with qualitative analysis.

Brown, T. L., H. E. LeMay, and B. E. Burstein. *Laboratory Experiments for the 6th Edition of Chemistry, The Central Science*. Englewood Cliffs, NJ: Prentice-Hall, 1994. Contains 40 experiments with supplementary material on techniques.

Chemical Education Resources, Inc. *Modular Laboratory Program in Chemistry*. 1992 catalog. This program, mostly macroscale, allows instructors to package their own laboratory manuals by selecting individual experiment modules that are indexed to particular portions of

the curriculum. Recent additions to the extensive list include new introductory-level experiments and a few microscale versions of experiments.

Ehrenkranz, D., and J. J. Mauch. *Chemistry in Microscale*, 2nd ed. Dubuque, IA: Kendall/Hunt, 1996.

Hall, J. F. *Experimental Chemistry*, 4th ed. Boston: Houghton Mifflin, 1997. A comprehensive manual with extensive introductions and *Choices* for instructor variations or possible extensions to experiments.

Hunt, H. R., and T. F. Block. *Laboratory Experiments for General Chemistry*, 3rd ed. Fort Worth: Saunders, 1997. Contains 42 experiments. An instructor's manual is also available to help in setup.

Marcus, S. T., M. J. Sienko, and R. A. Plane. *Experimental General Chemistry.* New York: McGraw-Hill, 1988. A small-format, very comprehensive manual with 52 general, 11 organic, and several qualitative-analysis scheme experiments.

Milio, F. R., N. W. G. Debye, and C. Metz. *Experiments in Chemistry*, Philadelphia: Saunders, 1991. Contains 44 experiments applying principles in the laboratory. Designed to be a comprehensive program with substantial theory included in introductory sections.

Mills, J. L., and M. D. Hampton. *Microscale and Macroscale Experiments for General Chemistry.* New York: McGraw-Hill, 1991. Contains 25 microscale and 15 macroscale experiments for a full two-semester course.

Mills, J. L., and M. D. Hampton. *Microscale Experiments for General Chemistry.* New York: McGraw-Hill, 1991.

Neidig, A. H., and W. J. Stratton. *Modern Experiments for Introductory Chemistry*, 2nd ed. Easton, PA: American Chemical Society, 1989. Selected experiments from the *Journal of Chemical Education.* Not student ready, but inspirational.

Peck, L., and K. J. Irgolic. *Measurement and Synthesis in the Chemistry Laboratory*, 2nd ed. Upper Saddle River, NJ: Prentice Hall, 1998. Contains 35 experiments in a new style format with complete concept introduction and operations sections.

Pickering, Miles. *The Rediscovery Book.* Glenview, IL: Scott Foresman/Little Brown Higher Education Division, 1990. A different style of manual with question-and-answer format. Contains 25 experiments, some laboratory practical exams, and other suggestions for a more conceptual approach to the laboratory.

Pribula, A. J. *Laboratory Experiments for General Chemistry.* New York: Scientific American Press, 1989. Contains 41 qualitative and quantitative experiments designed to accompany the text by Atkins and Beran.

Roberts, J. L., J. L. Hollenberg, and J. M. Postma. *Chemistry in the Laboratory*, 4th ed. New York: Freeman, 1997. A comprehensive and stand-alone manual coordinated with the McQuarrie and Rock textbook in the classic Frantz/Malm style.

Russo, T. *Microchemistry Teacher's Reference Manual.* West Chester, OH: Kemtec, 1989.

The Microscale Laboratory. *Journal of Chemical Education.* A regular feature.

C. Safety

Care and Handling of Laboratory Glassware. Corning Glassworks, Corning, NY 14831. (Free)

ChemAlert poster. Fisher Scientific - EMD, 4990 W. LeMoyne St., Chicago, IL 60605. (Free)

Chemical Storage Chart. Fisher Scientific - EMD (see above). (Free)

Design of Safe Chemical Labs. Brochure. American Chemical Society, 1155 16th St., N.W., Washington DC 20036. (Free)

Eye Safety is No Accident. National Society to Prevent Blindness, New York, 1980.

Flinn Scientific Reference Manual and Catalog. Flinn Scientific, Batavia, IL.

Hazardous Wastes from Homes. Enterprise for Education, Santa Monica, CA, 1991.

Jump Start Instruction. National Society to Prevent Blindness (see above). (Free)

Laboratory Safety Supply Catalog. Lab Safety Supply Company, Janesville, WI. (Free)

Pocket Emergency Handbook. National Safety Council Ave., 444 N. Michigan Ave., Chicago, IL 60651. ($4.50 for 10)

Safety in the High School Chemunity. American Chemical Society (see above). (Free)

Safety Brochures and Posters. National Safety Council (see above). Many different items.

Safety in Academic Chemistry Laboratories. American Chemical Society, Washington, DC, 1995.

Safety Manual and Catalog. Fisher Scientific (see above). (Free)

Speaking of Safety. Newsletter. Laboratory Safety Workshop, Curry College, Milton, MA 02186. (Free)

Answer Key to Multiple-Choice Questions

1 – C	7 – D	13 – B	19 – C	25 – C
2 – E	8 – D	14 – D	20 – D	26 – C
3 – A	9 – E	15 – A	21 – E	27 – D
4 – E	10 – B	16 – D	22 – B	28 – E
5 – C	11 – B	17 – B	23 – A	29 – D
6 – B	12 – D	18 – B	24 – A	

Distribution of Grades for All 1998 AP Chemistry Candidates

	Examination Grade	*Percentage Earning Grade*
Extremely Well Qualified	5	16.3
Well Qualified	4	13.9
Qualified	3	28.1
Possibly Qualified	2	21.3
No Recommendation	1	20.4

Mean Grade	2.84
Standard Deviation	1.34
Number of Candidates	44,937
Number of Schools	4,397
Number of Colleges Receiving AP Grade Reports	1,515

Why Colleges Give Credit for AP Grades

Colleges must be reasonably certain that the AP grades they receive represent a level of achievement equivalent to that of students who take the same course in the colleges' own classrooms. That equivalency is assured through several processes, including the presence of college faculty on the committees that develop the course descriptions and examinations in each AP subject, and by the predominance of college faculty on standard-setting committees and in the grading of students' responses on the AP Exams. Every four years, AP courses and exams are updated, based on results of curriculum surveys at up to 200 colleges and universities. Also, through college comparability studies, the performance of college students on AP Exams is compared with that of AP students to confirm that the AP grade scale of 1-5 is properly aligned with current college standards.

In addition, the College Board has commissioned studies that use a "bottom line" approach to validating AP Exam grades by comparing the achievement of AP versus non-AP students in higher-level college courses. Students who are exempted from introductory courses on the basis of their AP grades and who complete a higher-level course in college are compared, on the basis of their college grades, with students who completed the prerequisite first course in college, then took the second, higher-level course in the subject area. These studies answer the question of greatest concern to colleges — are their AP students who are exempted from introductory courses as well prepared to continue in a subject area as students who took the first course in college?

The data that follow provide a direct response to the question of the quality of AP students' preparation and their readiness to move immediately into more advanced coursework. A study of 20 colleges compared, in higher-level courses, the grades of AP-exempted students versus the grades of students in the same courses who successfully completed the first course in college. Each AP subject is reported for a subset of the 20 institutions in the study since some institutions do not have a clear sequence of courses from prerequisite to higher-level courses in certain subject areas.

The institutions participating in the study were: Boston College, Brigham Young University, Carnegie Mellon University, Clemson University, College of William and Mary, Cornell University, Duke University, Michigan State University, Penn State University, Stanford University, Tulane University, University of California at Davis, University of California at Irvine, University of Georgia, University of Illinois, University of Texas at Austin, University of North Carolina at Chapel Hill, University of Utah, University of Virginia, and Yale University.

Performance of Chemistry Students in Higher-Level Courses (11 institutions)		
AP Students Exempted from Lower-Level Course	**Average Grade**	**Percent earning A or B**
AP 5	3.38	87
AP 4	3.05	78
AP 3	2.98	74
	Average Grade	**Percent earning A or B**
Non-AP Students Who Took Lower-Level Course in College	2.78	63

The above table shows that AP students who received grades of 5 achieved, on average, strong grades in higher-level courses, with 87 percent earning an A or B in that course. All AP-exempted students showed significantly higher grades and percentages of As and Bs than students who took the prerequisite course in college.

The AP Reading

In June, the free-response sections of the exams, as well as the portfolios in Studio Art, are scored by college and secondary school teachers at the AP Reading. In 1999, more than 4,000 of these faculty consultants will participate in the Reading, under the direction of a Chief Faculty Consultant in each field. The experience offers both significant professional development and a network of like-minded educators; if you are an AP teacher or a member of a college faculty and would like to serve as a faculty consultant, you can apply online (go to the "Teachers" or "Colleges and Universities" section of our website at www.collegeboard.org/ap). Alternatively, send an e-mail message to apreader@ets.org, or call Performance Scoring Services at (609) 406-5383.

AP Grades

The faculty consultants' judgments on the essay and problem-solving questions are combined with the results of computer-scored multiple-choice questions, and the total raw scores are converted by the Chief Faculty Consultants to the Program's 5-point scale:

AP GRADE	QUALIFICATION
5	Extremely Well Qualified
4	Well Qualified
3	Qualified
2	Possibly Qualified
1	No Recommendation

Numerous quality-assurance procedures have been developed over the more than 40 years that the Program has been operating. Information on AP grade validity, comparability, and procedures is available online in the "Technical Corner" of our website, or in a number of AP publications, including *Grading, Interpreting, and Using Advanced Placement Examinations* (see the back of this booklet for ordering information).

AP and College Credit

Colleges are responsible for setting their own policies regarding how much credit, if any, they grant for AP grades. If you are an admissions administrator and need guidance on setting a policy for your college, you will find the *College and University Guide to the Advanced Placement Program* useful; see the back of this booklet for ordering information. This *Guide* can also be ordered online through the AP aisle of the College Board Online® store (http://cbweb2.collegeboard.org/shopping). Alternatively, contact your local College Board Regional Office, or Frederick Wright or Wade Curry at the National Office, as noted on the inside back cover of this booklet.

Students or teachers wishing to find out a particular college's policy regarding the granting of AP credit can make use of an online resource known as College Search. Maintained by the College Board through its Annual Survey of Colleges, College Search can be accessed via the College Board's home page (www.collegeboard.org). When you get to the main College Search page, choose your degree level, select "Search by Name," then "See College Info", and then choose the option "Academics." It is worth remembering, though, that policies are subject to change, and you should contact the college directly to be sure of getting the most up-to-date information.

AP Search

High school sophomores and juniors who received grades ranging from 2 to 5 on AP Exams taken in May of the preceding school year are identified to participating colleges and universities through descriptive questionnaires completed voluntarily by the students.

AP Scholar Awards and the AP International Diploma for Overseas Study

The AP Program offers a number of awards to recognize high school students who have demonstrated college-level achievement through AP courses and exams. In addition, the AP International Diploma for Overseas Study (APID) certifies the achievement of successful AP candidates who plan to apply to a university outside the United States.

For detailed information on AP Scholar Awards and the APID, including qualification criteria, visit the "Students and Parents" section of our website. Alternatively, contact Phil Arbolino (Scholar Awards) or Charlotte Gill (APID) at the College Board National Office (see the inside back cover for contact information). Students' questions are also answered in the *AP Bulletin for Students and Parents*; go to the back of this booklet for ordering information.

AP Calendar of Testing Activities

The AP Exams are administered to students by their high schools each May. Below is a list of the major activities that occur in conjunction with the exam administration.

September: Participation Forms are sent with a survey and request for AP teachers' names.

October/November: Secondary schools indicate their intention to participate, and name their AP Coordinator. AP Coordinators return participation materials to ETS by November 15. ETS mails a supply of the *AP Bulletin for Students and Parents* and other information to schools.

Throughout the Year: Additional mailings to schools may occur in specific subject areas if there are significant changes in exam format or curricula.

February: AP Coordinators receive Examination and Special Services Order Forms and Fee Reduction Request Forms. Announcements of upcoming summer institutes are mailed out.

March 1–April 1: AP Coordinators return Examination and Special Services Order Forms and Fee Reduction Request Forms to ETS.

April: AP Coordinators receive, and should check, exam materials.

April–May: AP schools are sent Course Descriptions for the next academic year based on their current year's exam order.

May 10-14 and 17-21, 1999: AP Exams are administered.

June 1: Last date for submitting AP fees.

June: Free-response sections, tapes, and Studio Art portfolios are scored by more than 4,000 high school and college faculty consultants.

June 15: Deadline for ETS to receive student letters to cancel grades, change college grade report recipients, or withhold grades. $100 late fee charged to schools that have not submitted payment.

July 1: Grades by Phone available for 1999 administration.

July: AP grades are sent to students' designated colleges as well as their schools and home addresses.

Late August: The *Report to AP Teachers* is sent to high schools for subjects in which five or more students took the exam.

August–September: Announcements of upcoming AP workshops are mailed out.

September: International Diploma and Scholar Award notifications sent to students and schools.

November: State and National Summary Reports and the *AP Yearbook* are sent to school principals and college administrators.

November–December: Free-response booklets are available to secondary schools.

> *Alternate Exam Notes:* Free-response booklets are **not** available for students who tested late using an alternate form of the exam, and their grade reports may be delayed up to one month (August release).

Test Security

The entire AP Exam is considered to be secure until the scheduled administration date. Except during the actual exam administration, exam materials must be placed in locked storage. Forty-eight hours after the exam has been administered, the green and blue inserts from the free-response section (Section II) are available for teacher and student review.* **However, the multiple-choice section (Section I) MUST remain secure both before and after the exam administration.** No one other than candidates taking the exam can ever have access to or see the questions contained in this section — this includes AP Coordinators and AP teachers. The multiple-choice section must never be shared or copied in any manner.

While some multiple-choice questions are published periodically, it is imperative that the security of these exam materials is maintained. Various combinations of selected multiple-choice questions are reused from year to year to provide an essential method of establishing high exam reliability, controlled levels of difficulty, and comparability with earlier exams. These goals can only be attained when the multiple-choice questions remain secure. This is why teachers cannot view the questions and students cannot share information about these questions with anyone following the exam administration.

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*The alternate (make-up) form of the free-response section is NOT released.

To ensure that all students have an equal chance to perform on the exam, all AP Exams must be administered in a uniform manner. It is extremely important to follow the administration schedule and all procedures outlined in detail in the most recent *AP Coordinator's Manual*. The manual also includes guidelines, which must be followed, on how to deal with misconduct and other security problems. Any breach of security should be reported immediately through the test security hotline (call 1-800-353-8570 or e-mail tsreturns@ets.org).

Teacher Support

There are a number of publications and videos available to supplement this Course Description, including Teacher's Guides and Released Exams. For details and ordering information, see the following pages or go to the AP aisle of the College Board Online store (http://cbweb2.collegeboard.org/shopping). In addition, many teachers find the following resources to be invaluable.

- **AP workshops and summer institutes.** New and experienced AP teachers are invited to attend workshops and seminars to learn the rudiments of teaching an AP course as well as the latest in each course's expectations. Sessions of one day to several weeks in length are held year-round. Dates, locations, topics, and fees are available through the College Board's Regional Offices, in the publication *Graduate Summer Courses and Institutes* (see the following page for ordering information), or in the "Teachers" section of our website.
- **AP videoconferences.** Several videoconferences are held each year so that AP teachers can converse electronically with the high school and college teachers who develop AP courses and exams. Schools that participate in the AP Program are notified of the time, date, and subject of the videoconference in advance. Videotapes of each conference are available shortly after the event; see the following section for ordering information.
- **Online discussion groups.** The AP Program has developed an electronic mailing list for each AP subject. Many AP teachers find this free resource to be an invaluable tool for sharing ideas with colleagues on syllabi, course texts, teaching techniques, and so on, and for discussing other AP issues and topics as they arise. To find out how to subscribe, go to the "Teachers" section of our website.

AP Publications and Videos

A number of AP publications and videos are available to help students, parents, AP Coordinators, and high school and college faculty learn more about the AP Program and the courses and exams that are available. To sort out those publications that may be of particular use to you, refer to the following key:

Students and Parents	**SP**	**AP Coordinators and Administrators**	**A**
Teachers	**T**	**College Faculty**	**C**

You can order many items online through the AP Aisle of the College Board Online store at http://cbweb2.collegeboard.org/shopping/. Alternatively, call AP Order Services at (609) 771-7243. American Express, VISA, and MasterCard are accepted for payment.

If you are mailing your order, send it to the Advanced Placement Program, Dept. E-05, P.O. Box 6670, Princeton, NJ 08541-6670. Payment must accompany all orders not on an institutional purchase order or credit card, and checks should be made payable to the College Board. The College Board pays fourth-class book rate postage (or its equivalent) on all prepaid orders; you should allow between four and six weeks for delivery. Postage will be charged on all orders requiring billing and/or requesting a faster method of shipment.

Publications may be returned within 15 days of receipt if postage is prepaid and publications are in resalable condition and still in print. Unless otherwise specified**, orders will be filled with the currently available edition**; prices are subject to change with-out notice.

AP Bulletin for Students and Parents: Free **SP**

This bulletin provides a general description of the AP Program, including policies and procedures for preparing to take the exams, and registering for the AP courses. It describes each AP Exam, lists the advantages of taking the exams, describes the grade and award options available to students, and includes the upcoming exam schedule.

College and University Guide to the AP Program: $10 **C, A**

This guide is intended to help college and university faculty and administrators understand the benefits of having a coherent, equitable AP policy. Topics included are validity of AP grades; developing and maintaining scoring standards; ensuring equivalent achievement; state legislation supporting AP; and quantitative profiles of AP students by each AP subject.

The College Handbook with College Explorer® CD-ROM: $25.95 **SP, T, A, C**

Includes brief outlines of AP placement and credit policies at two- and four-year colleges across the country. Notes number of freshmen granted placement and/or credit for AP in the prior year.

Course Descriptions: $12 **SP, T, A, C**

Course Descriptions provide an outline of the AP course content, explain the kinds of skills students are expected to demonstrate in the corresponding introductory college-level course, and describe the AP Exam. They also provide sample multiple-choice questions with an answer key, as well as sample free-response questions. A set of Course Descriptions is available for $100. Not included in this set are Course Descriptions for Computer Science, Government and Politics, and Statistics, which are available for downloading from the AP section of the College Board website (free of charge).

Five-Year Set of Free-Response Questions: $5 **T**

This is our no-frills publication. Each booklet contains copies of all the free-response questions from the last five exams in its subject; nothing more, nothing less. Collectively, the questions represent a comprehensive sampling of the concepts assessed on the exam in recent years and will give teachers plenty of materials to use for essay-writing or problem-solving practice during the year. (If there have been any content changes to the exam in the past five years, it will be noted on the cover of the booklet.)

Free-Response Question booklets: $12 **T**

Free-Response Question booklets contain one-year's worth of free-response questions, taken directly from the AP Exam, along with the guidelines used to score the student responses, and samples of those responses. Teachers find the Free-Response Question booklets useful for essay-writing and problem-solving practice or testing during the year. Subjects with an audio component (French, German, Spanish, and Music) include a cassette. Various years (up to 1997) available, depending on subject.

Grading, Interpreting, and Using Advanced Placement Examinations: Free **A, C, T**

A booklet containing information on the development of scoring standards, the AP Reading, grade-setting procedures, and suggestions on how to interpret AP grades.

Guide to the Advanced Placement Program: Free **A**

Written for both administrators and AP Coordinators, this guide is divided into two sections. The first section provides general information about the AP Program, such as how to organize an AP Program, the kind of training and support that is available for AP teachers, and a look at the AP Exams and grades. The second section contains more specific details about testing procedures and policies and is intended for AP Coordinators.

Released Exams: $20
($30 for "double" subjects: Calculus, Physics) **T**

About every four years, on a staggered schedule, the AP Program releases a complete copy (multiple-choice and free-response sections) of each exam. In addition to providing the multiple-choice questions and answers, the publication describes the process of scoring the free-response questions and includes examples of students' actual responses, the scoring standards, and commentary that explains why the responses received the scores they did.

For each subject with a released exam, you can purchase a packet of 10 copies of that year's exams ($30) for use in your classroom (e.g., to simulate an AP Exam administration).

Secondary School Guide to the AP Program: $10 **A, T**

This guide is a comprehensive consideration of the AP Program. It covers topics such as: developing or expanding an AP program; gaining faculty, administration, and community support; AP grade reports, their use and interpretation; AP Scholar Awards; receiving college credit for AP; AP teacher training resources; descriptions of successful AP programs in nine schools around the country; and "Voices of Experience," a collection of ideas and tips from AP teachers and administrators.

Student Guides
(available for Calculus, English,
European History, and U.S. History): $12 **SP**

These are course and exam preparation manuals designed for high school students who are thinking about or taking a specific AP course. Each guide answers questions about the AP course and exam, suggests helpful study resources and test-taking strategies, provides sample test questions with answers, and discusses how the free-response questions are scored.

Teacher's Guides: $12 **T**

Whether you're about to teach an AP course for the first time, or you've done it for years but would like to get some fresh ideas for your classroom, the Teacher's Guide can be your adviser. It contains syllabi developed by high school teachers currently teaching the AP course and college faculty who teach the equivalent course at their institution. Along with detailed course outlines and innovative teaching tips, you'll also find extensive lists of recommended teaching resources.

Videoconference Tapes: $15 **SP, T, C**

AP conducts live, interactive videoconferences for various subjects, enabling AP teachers and students to talk directly with the Development Committees that design the AP Exams. Tapes of these events are available in VHS format and are approximately 90 minutes long.

AP Pathway to Success (video — available in English and Spanish): $15 **SP, T, A, C**

This 25-minute-long video takes a look at the AP Program through the eyes of people who know AP: students, parents, teachers, and college admissions staff. They answer such questions as "Why Do It?", "Who teaches AP Courses?", and "Is AP For You?". College students discuss the advantages they gained through taking AP, such as academic self-confidence, writing skills, and course credit. AP teachers explain what the challenge of teaching AP courses means to them and their school, and admissions staff explain how they view students who have stretched themselves by taking AP Exams. There is also a discussion of the impact that an AP Program has on an entire school and its community, and a look at resources available to help AP teachers, such as regional workshops, teacher conferences, and summer institutes.

What's in a Grade? (video): $15 **T, C**

AP Exams are composed of multiple-choice questions (scored by computer), and free-response questions that are scored by qualified professors and teachers. This video presents a behind-the-scenes look at the scoring process featuring footage shot on location at the 1992 AP Reading at Clemson University and other Reading sites. Using the AP European History Exam as a basis, the video documents the scoring process. It shows AP faculty consultants in action as they engage in scholarly debate to define precise scoring standards, then train others to recognize and apply those standards. Footage of other subjects, interviews with AP faculty consultants, and explanatory graphics round out the video.

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